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ABSTRACT

This review has a section devoted to each of the following conference topics: Monographs, Film, Experiment Sequences, Computer-assisted Instruction, Designing a Unit of Instruction, and Toward New Solutions. Each section contains background discussion on the rationale, philosophy, and importance for improvements in the area being considered. The materials developed at the conference are described, and include multi-level monographs, film on symmetry and computer generated film; experimental sequences on oscillators and normal modes; kinetic theory; and properties of matter. Brief examples of computer-assisted program sequences on weightlessness and optics are presented, as is a list of conference participants. Photographs. (PR)

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TITLE PAGE

INSTRUCTION BY DESIGN

A REPORT ON THE CONFERENCE ON

NEW INSTRUCTIONAL MATERIALS IN PHYSICS

HELD AT THE

UNIVERSITY OF WASHINGTON

SUMMER, 1965

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

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SE 007 673

The Conference on New Instructional Materials in Physics was held at the University of Washington from June 21 to August 21, 1965. It was supported by the National Science Foundation and sponsored by the Commission on College Physics and the University of Washington physics department. Edward D. Lambe, Chairman of the Panel on the New Instructional Materials, Commission on College Physics, and Ernest M. Henley, of the University of Washington physics department, were co-directors.

The project drew together some forty physicists and a dozen or so film makers and designers in an effort to create effective ways of presenting physics to college students who are not preparing to become professional physicists. Such an audience might include prospective secondary school physics teachers, prospective practitioners of other sciences, and those who simply wish to study physics as one component of a liberal education.

Conference participants, more than half of whom attended for the full nine weeks, worked in a wide variety of presentational media. This report describes what was accomplished in each.

Contents

Monographs 5
A majority of the physicists devoted their time to writing multi-level monographs, and preliminary versions of these were prepared during the summer. The easy availability of interested colleagues and small test-groups of students made it possible for authors to get rapid response to their ideas and rough drafts.

Film 11
Although no instructional films were produced during the summer, scripts were written, trial footage shot, and ideas outlined. Some of the film work begun at Seattle is still in progress, and a film on symmetry, with many novel elements of concept and design, is forthcoming. An unusual activity was the preparation of computer-generated film, and a number of sequences suitable for short film loops were produced.

Experiment Sequences 19
Observations of real phenomena can serve a student as the basis for understanding important physical concepts and principles. Experiment sequences were designed to introduce and amplify ideas in three distinct areas: oscillators and normal modes, kinetic theory, properties of matter.

Computer-assisted Instruction 29
A number of participants explored the capabilities of real time, terminal-oriented computers as components of instructional systems. Preliminary versions of materials were developed and programmed. These include diagnostic tests, remedial units, and a lab unit in geometrical optics.

Designing a Unit of Instruction 37
A team of physicists, designers, and film makers worked for one week to test the possibilities of closely collaborative, cross-disciplinary design. Taking as their problem an improved approach to the elementary ideas of motion, they produced a structural plan, a number of supplementary schemes and gadgets, and some deeply felt opinions about the process they were engaged in.

Toward New Solutions 43
The approach to improvement of undergraduate physics instruction consists in large measure of a search for instructional working models. Some such models were created at Seattle, and something was learned about how to create others, and what kind they should be.

Participants 46

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Monographs

The Conference on New Instructional Materials was familiarly known as "the physics writing conference." This was hardly surprising. Writing was the task in which most physicists participated, and the bulk of the Conference's tangible production consists of the eighteen monographs listed on pages 8 and 9.

Admittedly the preparation of monographs is not an activity that connotes the bold search for freshness and new life to which the Seattle conference was committed. Yet its very conventionality makes the monograph a logical basic module for structuring such a conference: it is an instrument with which most physicists are familiar, and with which some have demonstrable skill. Writing is a practical way to begin, since it allows a participant to choose a manageable subject and control its handling. Usually a solitary craft, it need not involve close collaboration with anyone outside academic life. Required facilities are minimal. In the first weeks of the conference, necessarily exploratory weeks where such exotic modes as film were concerned, the writers had nothing to explore but the content.

Their goal was to produce a set of fresh and compellingly written papers, each directed, by choice of subject and by style, to the new audience envisioned.

The multi-level concept

One of the most troublesome problems facing the Commission's Panel on New Instructional Materials is how to find ways of introducing new materials into ongoing curricula, both for use and for evaluation. As at least a partial solution, it was proposed that the monographs be "multi-level," each monograph consisting of from two to four sections, arranged in increasing levels of sophistication. Thus a single monograph could serve a variety of pedagogical purposes, depending on an

instructor's needs. Furthermore, corresponding sections of many monographs might be assembled and organized into a coherent unit. A collection of introductions, for example, could serve as the basis for a survey course.

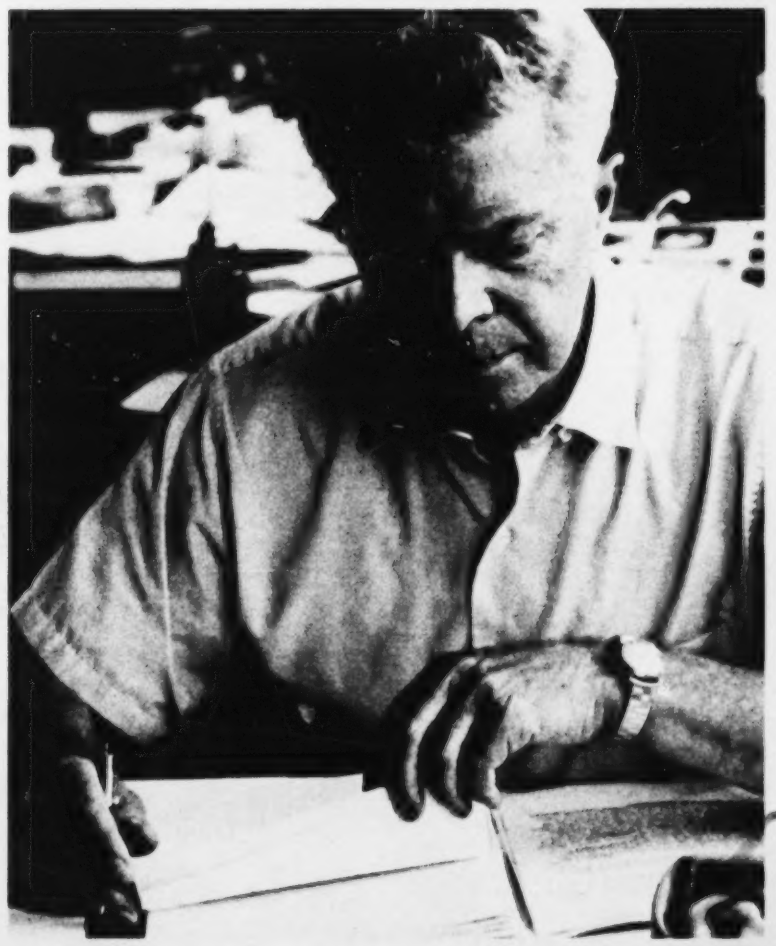
While the chief aim of multi-level writing is to amplify the utility of a body of material by making it useful to several kinds of students, there are also advantages apparent in having material of various levels available to the *same* student. If, for example, a student has been assigned second-level material for study, he may be able to use the more elementary first-level section for review. What is more important, he has access to material of greater complexity at the third level, and its inclusion in the monograph can evoke his curiosity. An unusual student may be able to go further than his instructor supposes. But whether he can cope with the material or not, he does see, at any rate, that to have "covered" the subject is not to have plumbed its depths, or even to have outlined all of its ramifications.

In a general way, monograph content was organized into the four subject-matter areas found most promising at the Aspen Conference of 1964:

1. Forces and Fields — basic concepts in mechanics and electromagnetism
2. Thermal and Statistical Physics — thermodynamics, kinetic theory, statistical mechanics
3. Structure and Properties of Matter — connections between atomic and microscopic properties
4. Quantum Mechanics — relation of quantum mechanical concepts to phenomena and to classical concepts

After writers chose their topics, group leaders were appointed for each of the four areas, and charged with directing activities and planning the work "in detailed consultation with members of their group and others." But direction was in fact minimal; and although a certain fidelity to the multi-level concept was encouraged, not many of the monographs produced were written along the parallel lines described above. (The concept, like other aspects of the Seattle project, is still evolving, and in some cases it made more sense to ignore it than to try to follow it slavishly into areas where its application was not clear.) The multi-level monograph as originally proposed turned out to be extremely difficult to create. For that matter, it was from the first extremely difficult to describe. To make description easier — actually to bypass it as far as possible — Alan Holden, of Bell Telephone Laboratories, had been asked in February, 1965, to prepare a sample that could be reviewed before Seattle.

In response, Holden outlined a series of three monographs and, with the generous cooperation of Bell Telephone Laboratories, was able to complete one of them — "Bonds Between Atoms" — in April. It was neither taken nor meant to be taken as a pattern for Seattle; but it was sent to



all participants before the Conference began, and the simple fact of its existence helped clarify the multi-level concept. Another sample distributed to writers, because it was thought to have an appropriate flavor, was a pre-print of the chapter on special relativity from Arnold Arons' *Developments of Concepts of Physics* (Addison-Wesley, 1965).

Interaction, feedback, trial

Although the plans called for monographs to "fit into a defined sequence," that sequence was never actually defined, since an outline of even reasonable breadth would have been too broad to be filled in by the summer's output in any case. Authors therefore were able to choose topics without regard for what other authors might be planning. In practice, however, a number of monographs do relate to one another, and details of the relationship were worked out informally. Though not conceived as a unit, the Cotts-Detenbeck monograph on "Matter in Motion" and the Gerhart-Nussbaum monograph on "Motion" are, on the basis of close discussion by the respective writing teams, complementary. The Phillips monographs, "Electrostatics" and "Magnetostatics," and the Mara monograph, "The Circulation Laws," are the result of extremely close interaction between those two authors.

All manuscripts were of course read, at various stages, by helpful colleagues of the author. But as one author pointed out, "the proof of the pudding being in the eating, the approval of one's colleagues on a piece of writing can not replace the positive reaction of students actually using the material." In a unique attempt to make such reaction available, the Conference maintained a pool of student readers. Their function was to provide an author, while work was in progress, with some kind of substitute for the feedback he ordinarily gets from his own classes.

The need for feedback was intensified and complicated by the multi-level character of the writing. Some authors assumed the burden of addressing several student audiences in a single manuscript. The student pool was particularly valuable to them because it enabled them to "order" readers with precisely the desired background (or lack of background) in physics. Several authors tried their material out on students by lecturing briefly along the lines their monograph would take, then determining through discussion whether the approach promised to work as intended. Others sent out sections of monographs and asked for the student's tape-recorded comments. In other cases, students were required to work problems and take tests.

Ten of the authors made use of the student-reader service. In addition, the student pool was used for pre-testing computer programs, films, and demonstration apparatus. A total of 57 students put in 810 man hours at this activity.

All of the monographs are experimental and tentative, and in the opinion of their authors closer to clean first drafts than to final, polished manuscripts. The Commission on College Physics is selecting three physicists to prepare a formal review of each monograph. When all the reviews are in, eight or ten of the reviewers will meet to look carefully at the entire set, to make recommendations for such further development of individual monographs as they think suitable, and to make suggestions for student and faculty trial of the material.

In the meantime single copies of the monographs described overleaf are available on request to the Commission. Requests for larger numbers for class use should include some detailed description of the way in which they will be used.

Trial Monographs Available

The following trial monographs were produced at Seattle. Single copies are available on request to the Commission on College Physics, Physics and Astronomy Building, The University of Michigan, Ann Arbor, Michigan 48104. Requests for larger numbers should include details of the proposed class use.

Forces and Fields

Electricity and Magnetism — 130 pages. Melba N. Phillips, University of Chicago; Richard T. Mara, Gettysburg College.

Three interrelated monographs presented as a unit. The first two, "Electrostatics" (30 pages) and "Magnetostatics" (40 pages) by Melba Phillips; the third, "Circulation Laws and Their Consequences" (60 pages), by Richard T. Mara. Although the material is not divided precisely along undergraduate class divisions, the monographs have, at least in outline, a two-level organization consisting of "first course material" and "upper division course material." Each level may be followed through the entire sequence: the fundamental empirical laws of electricity and magnetism, concluding with electromagnetic interactions, including radiation.

Motion — 130 pages. James Gerhart, University of Washington; Rudi Nussbaum, Portland State College.

The intention was to treat general kinematics on three levels: a qualitative treatment of curvilinear motion, a qualitative treatment of special cases, a moving coordinate system. Only the first level and part of the second are represented in the section now available. The first level is meant for freshmen, and possibly sophomores, without much mathematical background.

Basic Themes of Physics — 50 pages. Edwin A. Uehling, University of Washington.

Not a multi-level monograph on a restricted topic, but rather the beginning of an introductory course for students unlikely to pursue careers in physics. It covers a wide range of basic material, including, in its present state, kinematics, dynamics, force, and gravitation. When complete it will include electricity, the atomic-molecular nature of matter, kinetic theory and thermodynamics, relativity and light.

Matter in Motion — 90 pages. Robert M. Cotts, Cornell University; Robert W. Detenbeck, University of Maryland.

This account of certain basic conservation principles is designed to supplement a physics text at the freshman level. The treatment stresses the importance of conservation laws of energy and momentum in understanding patterns of nature.

Interference and Diffraction — 50 pages. Marc H. Ross, University of Michigan.

The "multi-levelness" of this monograph consists in the fact that an elementary student can read it by skipping indicated sections of the advanced material. It begins with a review of elementary optics, showing how the formalism of optics can be used to deal with particle scattering. It also treats electron scattering from molecules. A section not yet complete will deal with proton-nucleon scattering.

Thermal and Statistical Physics

Experimental Introduction to Kinetic Theory — 30 pages. Harold Daw, University of New Mexico.

This monograph includes experiments bearing on molecular distributions and kinetic theory predictions, and is built around five main areas of investigation: 1) speed distributions, 2) free path distributions, 3) equipartition of energy, 4) gravitational separation, and 5) scattering angle distributions. (This material is also discussed on page 22.) Each area contains a number

of experimental sub-parts. Although the material is arranged in progressive order of difficulty, it is not multi-level: the entire monograph is aimed at the sophomore-junior level.

Distributions — 50 pages. Wayne A. Bowers, University of North Carolina.

Intended for students who have had an introductory course, this monograph introduces distributions in an attempt to prepare students for the statistical and probabilistic ideas they will encounter in later courses. Treatment progresses from a first non-mathematical chapter, through calculus. A final chapter, not yet complete, will treat applications in statistical mechanics.

Heat and Motion — 100 pages. Norman Pearlman, Purdue University.

Intended for use in the year following an introductory course, this monograph relates temperature and thermodynamic equilibrium to particle motion, time reversal, fluctuations and degrees of freedom.

Heat Motion in Matter — 30 pages. J. Gregory Dash, University of Washington.

This monograph of two elementary and two advanced chapters begins with an elementary treatment of kinetic theory and ends with some fairly advanced material, including distributions in phase space and the Maxwell-Boltzmann gas.

Structure and Properties of Matter

What Can the Matter Be? — 60 pages. Jack A. Soules, University of New Mexico.

This project consists of three sections: a text, a student guide to experiments, and an instructor's guide to other experiments. The student guide describes five experiments which have been built and tested (see page 23). The instructor's guide contains experiments which have been planned but not actually constructed, and suggests still others. Monograph is meant to prepare students for further work in kinetic theory, solid state, physical chemistry, and thermodynamics.

The Nature of Atoms — 50 pages. Alan Holden, Bell Telephone Laboratories.

The second of a series of three meant to be tested and evaluated together. Discusses the development of an atomic theory ultimately using quantum properties of orbiting electrons, beginning with materials presumably understandable to freshmen and ending with a treatment meant to be distinctly upper-class.

Bonds Between Atoms — 70 pages. Alan Holden, Bell Telephone Laboratories.

The last in a series of three meant to be tested and evaluated together. Deals specifically with chemical bonding, beginning with material presumably understandable to freshmen and ending with a treatment distinctly upper class.

Quantum Mechanics

Wave Mechanical Properties of Stationary States — 50 pages. Alan Holden, Bell Telephone Laboratories.

The first of a series of three monographs meant to be tested and evaluated together. Deals in a very general way with the quantum mechanical properties of stationary states, beginning with material presumably understandable to freshmen and ending with a treatment distinctly upper class.

Crucial Experiments in Quantum Physics — 40 pages. George L. Trigg, Brookhaven National Laboratory.

Descriptions and discussions of a number of experiments on quantum effects, chosen to enhance understanding of the phenomena and to provide some historical background of quantum theory. Not clearly multi-level, it should come after an introductory course.

Conceptual Foundation of Quantum Mechanics — 60 pages. Leonard Eisenbud, State University of New York at Stony Brook.

This monograph is the first section of a presentation of quantum mechanical concepts for the junior-senior level.

The Symmetry of Natural Laws — 20 pages. Laurie M. Brown, Northwestern University.

For advanced undergraduates or beginning graduate students. Covers the ideas of symmetry, invariance, and their connection with conservation laws in classical physics. A second chapter, not yet available, treats symmetry principles in quantum mechanical applications.

Film

The film makers at Seattle came technically equipped to shoot an entire motion picture, either animated or live action. Their role, however, was not making films but planning them. And their presence with that function in mind was consistent with the Conference's attempt to involve designers in pedagogical projects at the earliest stages of development, rather than to call on them to execute projects that physicists had already fully planned.

Planning a film, of course, means more than just talking about it. It requires the preparation of an outline, the writing of a script. Usually it calls for rough sketches and a storyboard — a sequential set of sketches or still photographs that visually outlines the action. Sometimes trial footage is shot as an instrument of planning.

There is no single acceptable model for beginning the production of a film, and individual film makers work in a large variety of ways. But even for film makers, who are accustomed to finding that each new project is nothing like the last, film planning at Seattle was an unusual experience. For one thing, no subjects had been chosen. For another, only one or two physicists had come to Seattle expressly to make a film; and, indeed, most had not seriously considered film making as a pedagogical activity.

To generate raw material for beginning, some of the physicists and all of the film makers had met in April. As a result of that meeting a number of physicists prepared outlines of film ideas, and these were discussed in fairly large group meetings during the first days of the Conference. There were film outlines for the following subjects: limits; eigenvalues and eigenfunctions; waves: velocity, wavelength, and frequency; eigenvalues of a quantum mechanical harmonic oscillator. (Some computer-animated footage for the last film had already been produced.)

The discussion groups, which included most Conference participants, were useful in stimulating interest in film projects and familiarizing physicists with the kind of initial information that film makers are likely to need. A similar objective — that of exposing physicists to the broadest possible range of filmic effects — lay behind the weekly screening of experimental films. The films shown (see page 17) were not physics films. They usually were not science films (when they were, it was coincidental). Nor were they "educational" films. They were chosen to represent the rich variety of contemporary film art.

After each screening, a discussion of the work was led by Richard Hartzell, director

of the film and design group. These sessions were as a rule the most animated and impassioned of the Conference discussions, partly because so many of the films were in themselves controversial. While viewers seemed to feel that by and large the films were entertaining, not everyone agreed that they were relevant to the problems at hand. Hartzell and other film makers argued that physicists could not expect to use film successfully until they had developed enough visual sophistication to respond sensitively to the medium. They held that the movies shown, while not directly related to physics pedagogy, could significantly enlarge the physicist's awareness of what film can do.

Computer-generated film

One aspect of the film efforts was in fact new to both physicists and film makers. This was computer-generated film — the computer calculating points or line segments and displaying them on a cathode ray tube, where they are photographed directly as animated line drawings.

The results, sometimes visually spectacular, captured the imagination of the film makers. Participating physicists found the technique equally exciting. Instructors have long searched for effective methods of bypassing the technical aspects of mathematics when teaching students of limited mathematical competence. One common method is to convey graphically a solution that a student can appreciate without having to understand the difficult steps that led to it. For instructors the problem has always been to get adequate time-dependent graphs. As a source of such graphs, computer animation promises to be a very useful tool.

The examples of computer animation made at Seattle are, to a film maker, fragments rather than films. Ten such fragments were carried to varying degrees of completion during the summer. Some of them represent ideas so complex, and so demanding of expensive computer time, that they will not be completed unless the computational time can be reduced. (Related work now in progress at Livermore may reveal some way of reducing it.) Others

are scheduled to be finished in time for use in the fall of 1966. The list on page 16 indicates the current status of each fragment.

Two participants, George Michael and Robert Cralle, both of Lawrence Radiation Laboratories, Livermore, California, spent all of their time working on computer-generated films. Computer specialists with a background in physics, Michael and Cralle imported a skeleton of the code they regularly use at Livermore, and reconstructed the display generator part of the code to make it compatible with the IBM 7094/7044 DCF system at the University of Washington's Research Computation Center.

Ordinarily Michael and Cralle produce computer-generated films by means of on-line interaction with a display unit. At Seattle an additional step was required. Material was put on a tape at the University of Washington campus, then sent to the Boeing Company's SC 4020 installation, where the film was exposed.

Such variables as the suitability of subject matter for programming, and the experience of individual physicists, dictated the way in which Michael and Cralle operated in any given instance, but normally the routine ran something like this: The physicist defined the problem and the teaching objective, and provided a mathematical description which Michael and Cralle transformed into a form suitable for short-term computation. After the mathematics of that version was checked by the physicists, Michael and Cralle did the programming.

The language problem

These films can be made by a physicist alone if he has taken the time to learn something about programming. In fact it is not wholly clear what role (if any) directors, writers, designers and others traditionally associated with the creation of motion pictures will play in computer-generated film production. Maurice Constant, one of the Conference film makers, prepared a paper analyzing the computer's possibilities from a film maker's point of view. His paper pays particular attention to the problem of creating a "movie language" that would enable a film maker (and, by implication, anyone else) to use the computer as a production instrument by communicating with it very directly.

The absence of such a language at present inhibits the production of fully developed, major computer-animated motion pictures. In November an *ad hoc* committee was formed of members of the

mathematics, engineering, and physics commissions, to help develop the art of computer animation. The Seattle contingent is represented on this committee.

The status lists on page 16 describe the tangible results of the film activity — the scripts written, the footage shot, the outlines ready for development. There are also intangible results, no less important for that. Among the most valuable of these are experience in collaborative film making, sensitivity to qualities that are uniquely filmic, and insights into ways of exploiting these qualities pedagogically.

A film about symmetry

A Seattle project richly illustrative of all these values is the design for an animated film about symmetry by animator Philip Stapp and physicists Judith Bregman, Richard Davisson, and Alan Holden. The description below, in the words of the authors, makes clear that, whatever the success of the finished product, its creators have collaborated intensely in an effort to make every decision faithful to both the requirements of pedagogy and the nature of film.

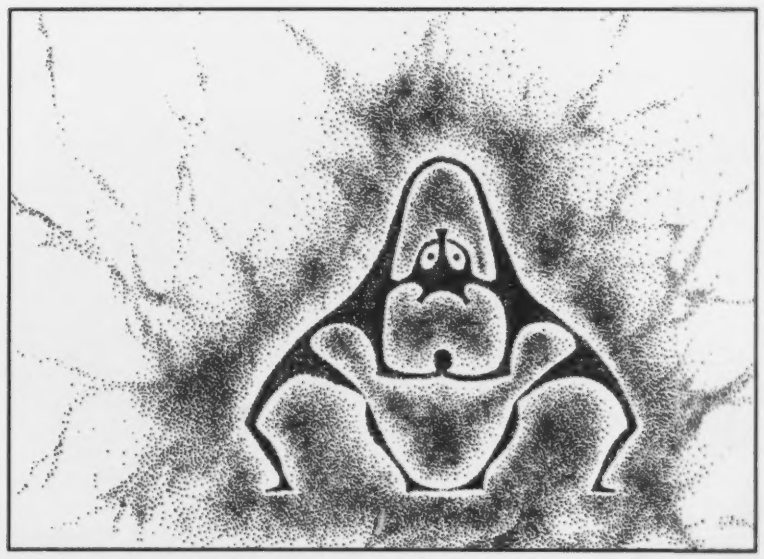
The visual imagery of the film evolves around one or more semi-abstract figures which are in continual motion subject to symmetry elements. These elements are never explicitly shown, but the arrangement and movements of the figures on the screen will display symmetries, and by implication define the symmetry elements: reflection, rotations and translation. The consequences of combining symmetry elements, both the restrictions on combinations of these elements and the completeness of groups of elements, will be shown, again by implication. The sequence will be from simple to more complex: in two dimensions from point groups to line groups, and lastly to plane groups.

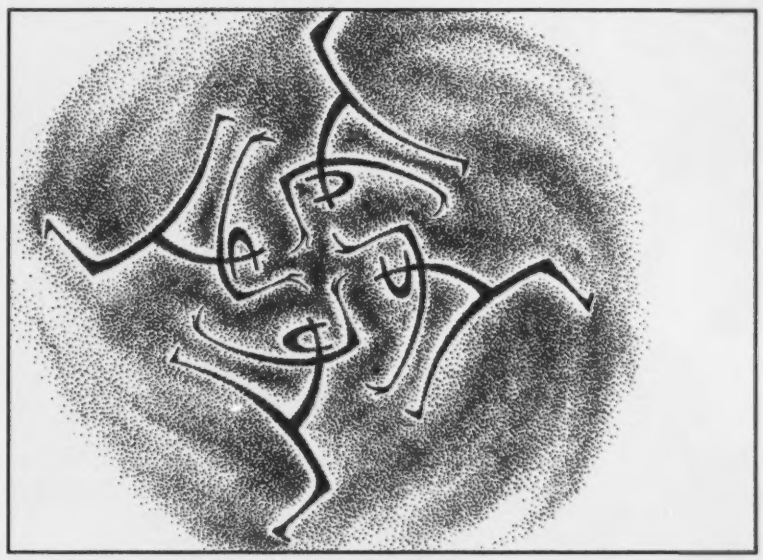
The advantages of the use of motion are several.

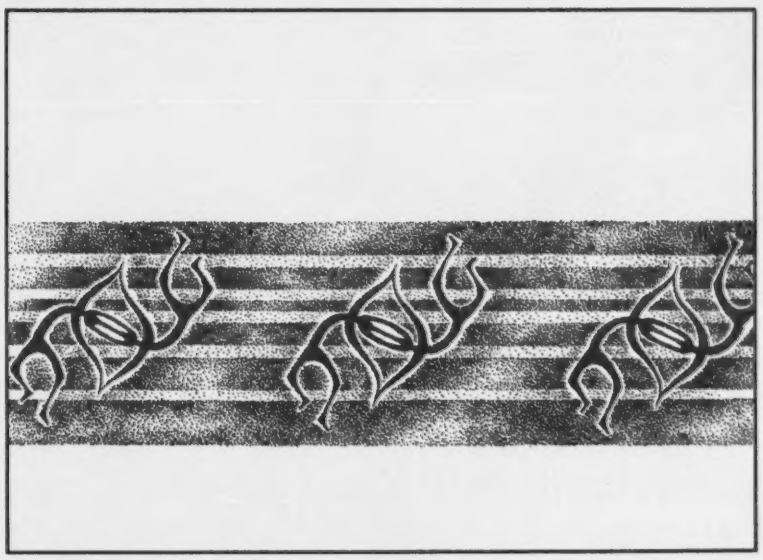
1. Through the movement of the figures the film will show immediately and vividly that a single symmetry element or a set of elements corresponds to many different arrangements of the figures.

2. The changing relations of the moving figures to each other will give dynamic illustration to the manner in which the position of the asymmetric unit controls the positions of the other units on the screen.

3. The relationships among the moving figures







Preliminary sketches drawn by Philip Stapp for animated film about symmetry. Film will have no narration.

will also bring out dynamic relations among symmetry elements, that the presence of two or more elements may produce other symmetry elements (a concept difficult for students). For example, the combination of two translations and a four-fold rotation axis produces two-fold rotation axes as well as four-fold rotation axes located differently in the unit cell from the original one and its translation-replicas. In the film, the moving figures will be seen to cluster in fours, to pass each other in pairs, and to recluster in fours at new locations.

There is to be no spoken narration; the film will depend on continual movement and music to present its subject. The nature of the movement and the timing will differ with different symmetries, and so characterize each and mark the transitions between them. The music, to be written for the film, will provide the basic rhythmic pulses, the timing upon which the movement develops. In addition, by changes in its quality and tone, the music will also characterize the symmetries, differentiate one type from another, or draw attention to a particular situation, as a speaker does by varying his tone of voice during a lecture. This use of music, as an essential part of the presentation, is unlike the customary usage in documentary and other films, where it is employed primarily as a background to create a mood.

As a teaching tool, the film is not intended to substitute for an organized presentation by a teacher or for later study by the students. It should, however, provide intuitive resources (visual exemplifications of symmetries) that students usually obtain only after actually working with symmetry concepts. In addition, the film can be used to teach on a less explicit level, to provide an awareness in students of methodology. The process of abstraction from the many patterns made by the moving figures to a few precisely defined concepts is demonstrated repeatedly: in the unseen 'symmetry elements' that restrict the varied motions of the figures on the screen, in the 'asymmetric unit' whose position and path must be specified, and in the 'unit cell,' the chosen repeat unit in the line and plane groups. The precision of the concepts is suggested by the controlled step-by-step progression from one symmetry group to another, and the strictness with which the moving figures in the film adhere to the symmetry rules. The generality of the concepts is suggested by the film's use of figures in motion to illustrate principles that the student may later apply to problems in physics.

The film contains more information than a beginner could be expected to comprehend in ten minutes, even though we are considering only two-dimensional geometric symmetries and not all of these. A short booklet will accompany the film. It will make explicit the principles shown implicitly and will include all the two-dimensional symmetry groups and suggest the extension to higher dimensions, and perhaps to other types of symmetries. The illustrations will include frames from the film. A copy of the booklet should be provided to each student. As a teaching aid, the film would probably be shown at least twice, with lectures given in between and afterwards.

The film was planned as part of a larger development of new instructional material for college physics students, in particular for majors who expect not to become professional physicists but to specialize later in other fields or perhaps to become high school teachers. The film may have much wider usefulness, as a teaching aid in any course — science, mathematics or engineering — where symmetry principles are taught. This includes courses for science majors and the science courses for non-science majors (which prospective elementary school teachers are likely to take). It will also be interesting to experiment with the use of this film in teaching geometric symmetry to both younger and older audiences. In addition, the film should be of considerable interest to persons concerned with the arts, since the spectator's experience will depend on the contrapuntal relationship of music, color and movement. Furthermore, since the nature of the subject matter and its presentation are not dated, the film may be expected to have continuing usefulness.

Since film is an art form, we have, as part of the experiment, attempted to preserve artistic validity in the presentation while maintaining the strict discipline of science. Symmetry may be a particularly fortunate subject for such an experiment because of its close relationship to both art and science, but the close connection itself suggests the suitability of this experiment in the search for new teaching techniques.

Status of Film Projects

1. *Symmetry I.* A ten-minute animated film showing geometric symmetries. Physics by Judith Bregman, Richard Davisson, Alan Holden; design and animation by Philip Stapp. The first storyboard was finished by summer's end. Since then the design has been re-worked and the continuation of the project funded by NSF. A second film, *Symmetry II*, which grew out of this project, has also been funded by NSF. *Symmetry I* should be ready for testing in the fall of 1966. For a fuller description, see page 14.

2. *Report Film.* This seventeen-minute impressionistic film by Harry Prichett is the first complete motion picture to result from the Conference. An informal report on visual aspects of the Seattle project, the film is intended to stimulate physicists by suggesting contemporary techniques not commonly used in physics films.

3. *Space-Time Cartography.* Nandor Balazs proposed to introduce special relativity by using Minkowski diagrams. Harry Prichett, designer-film maker, completed a design sketchbook for the film, and created slides to be used with a program of computer-assisted instruction intended to complement the film. Richard Mould prepared the physics for computer-assisted instruction. Jack Ludwig, writer, consulted throughout.

4. *Pucks On An Air Table.* Lucite pucks, moving over an air table in a manner illustrative of random motion, were filmed under the direction of Harold Daw, who built the apparatus and created the demonstrations. Daw showed the unedited footage at the January meeting of AAPT. He is editing the material into loops which will accompany his monograph (see page 8). A large number of strobe still photos and time-lapse photos were also taken, from which data have been derived, graphed, and published in the monograph. Harry Prichett styled the apparatus.

5. *Time Reversal.* Laurie Brown and Boris Jacobsohn worked with film maker Richard Meyer to produce a script for a twenty-five minute film using live action, demonstrations, and animation.

6. *Introduction To Motion.* Jeremy Lepard, film maker, completed the first draft of a script for a ten-minute, live-action film based on the first section of a monograph by James Gerhart and Rudi Nussbaum. Further work on the film will not be undertaken until there has been time for response to the monograph.

7. Outlines For Proposed Films:
   a. *Limits*, by Everett Hafner
   b. *Uncertainty—A Principle Common to All Waves*, by Robert Cotts
   c. *Gedanken Experiments*, by William Blanpied
   d. *Introduction to Position-Time Histories*, by Maurice Constant, with Arnold Arons
   e. *How Physics Laws Are Obtained*, by Arthur Herschman
   f. *The Principia*, a series by Alfred Bork
   g. *Galileo — An Ecology of the Man*, by Harry Woolf and Maurice Constant
   h. *Waves: Velocity, Wavelength, Frequency*, by Susan Presswood

Status of Computer-Generated Film Projects

In every case except the first film listed, George Michael and Robert Cralle, of Lawrence Radiation Laboratories, were collaborators with the author.

1. *Eigenvalues*, written by Arthur Herschman, directed and programmed by James Strickland, some design by John Neuhart.
2. *Damped Harmonic Oscillator*, written and partially programmed by Alfred Bork, designed by John Neuhart. Sample completed.
3. *Minimum Uncertainty Packet*, written by Leonard Eisenbud. Available in summer 1966.
4. *Motion of Ensemble in Phase Space*, written by Leonard Eisenbud. Available in summer 1966.

The following four films were carried almost to the point of filming at Seattle, but were held up because each would require hours of machine time:

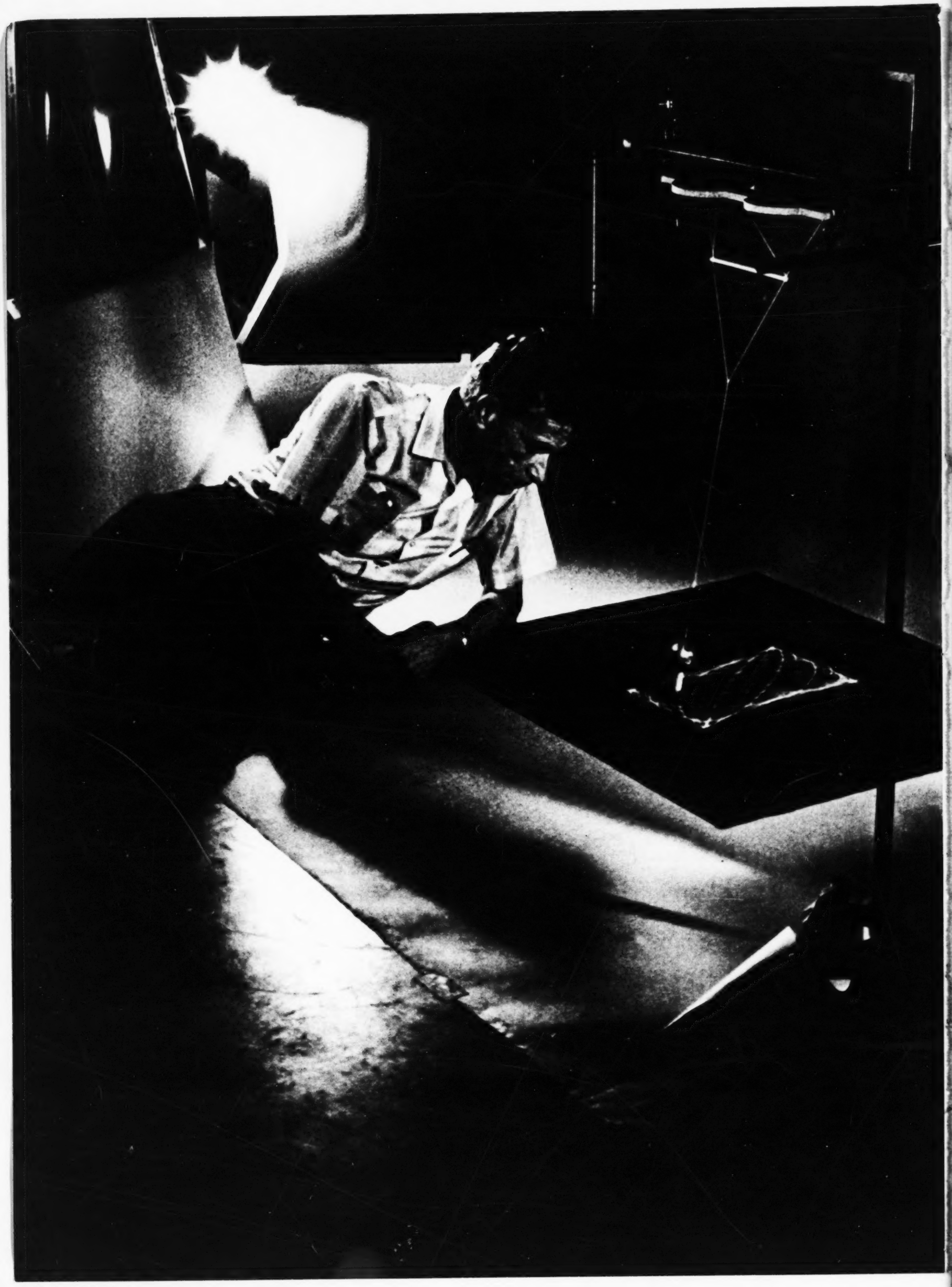
5. *Delta Function—Single Barrier*, by Arthur Herschman
6. *Delta Function—Double Barrier*, by Arthur Herschman
7. *Oscillating Pulse in a Box*, by A. Herschman
8. *Barrier Problem with Reflection*, by R. Mould

The final two films are complete but not yet prepared for distribution.

9. *Elastic Scattering of Relativistic Electrons*, by Noah Sherman
10. *Molecular Distribution* (Maxwell-Boltzmann), by Jack Soules

Films Shown

1. *A Scrap of Paper and a Piece of String*, by John Korty; distributed by Contemporary Films.
2. *Breaking the Habit*, by John Korty; distributed by the American Cancer Society and by Contemporary Films.
3. *Very Nice, Very Nice*, National Film Board of Canada.
4. Films by Norman McClaren, National Film Board of Canada:
   a. *A Chairy Tale*
   b. *Lines Horizontal*
   c. *Two Bagatelles*
   d. *Canon*
5. *A Smattering of Spots*—sample reel of television commercials, University of Washington AV Library.
6. *Motion Picture*, by Frank Paine; distributed by Southern Illinois University.
7. *Possibly So, Pythagoras*, by Bruce Cornwell; distributed by International Film Bureau.
8. *Universe*, National Film Board of Canada.
9. *Homage to Francois Couperin*, by Philip Stapp; available only from Mr. Stapp.
10. *Mathematica*, by Charles Eames; available from IBM. Five short films prepared as part of a museum display.
11. *Geometry Films*, by Trevor Fletcher; distributed by Cuisenaire, Inc.
    a. *Four Point Conics*
    b. *Plucked Strings*
    c. *The Simpson Line*
    d. *The Cardioid*
12. The Nicolet Animated Geometry Films; 22 very short films distributed by Cuisenaire, Inc.
13. *Clay* (or *Origin of the Species*) by Eliot Noyes, Jr.; distributed by Contemporary Films.
14. *The Loon's Necklace* by Crawley Films; distributed by Trans-World Films.
15. *Sky*, National Film Board of Canada.
16. *That's Me*, by Walker Stuart; distributed by Contemporary Films.
17. *Orange and Blue*, Carpenter Center for the Visual Arts, Harvard University; distributed by Contemporary Films.
18. *Pacific 231*, by Andre Tadie, Young America Films; distributed by McGraw-Hill.
19. *Guernica*, by Robert Flaherty; distributed by Museum of Modern Art, New York.
20. Computer Generated Animation — various samples from Bell Laboratories, Murray Hill, New Jersey and from Lawrence Radiation Laboratories, Livermore, California.
21. Films by Len Lye—an assortment of experimental films made in the early 1930's under the auspices of the Film Unit of the British Post Office. Distributed by the Museum of Modern Art, New York.
22. *Life of the Molds;* distributed by McGraw-Hill.
23. *Seifliz on Protoplasm*, made by William Seifliz with Churchill Films; distributed by Churchill Films.
24. *Art in Motion*, Encyclopedia Britannica Films.
25. *Can the Direction of the Flow of Time Be Determined?* Argonne National Laboratories. Three half-hour episodes.
26. *Introduction to Analog Computers*, Argonne National Laboratories. Three forty-minute episodes.
27. *Of Men and Stars*, by John Hubley with Harlow Shapley. A feature-length film.
28. The Feynman Lectures; film recordings of seven hour-long lectures delivered at Cornell University. Made by the BBC and obtained through ESI.
29. By Franklin Miller—19 short loops in 8mm cartridges, distributed by Educational Services Inc.
30. From Bell Labs—a. *Similarities in Wave Behavior;* b. *Ferro-magnetic Domain Behavior;* distributed by Bell System.
31. *Liquid Helium*, by Alfred Leitner, ESI.
32. College Physics Films—by ESI. a. 10 sound films. 23 short, silent, loops in 8mm cartridges.
33. National Committee for Fluid Mechanics Films—6 sound films and 15 short, silent loops in 8mm cartridges.
34. Films of the Physical Science Study Committee—53 sound films.
35. CHEM Study Films—26 sound films.



Experiment Sequences

For more than three centuries scientists have agreed with Francis Bacon that "man, who is the servant and interpreter of nature, can act and understand no further than he has observed, either in operation or in contemplation, of the method and order of nature." And any man's contemplation can be laughed out of court by another who shows that it implies behavior at variance with what actually happens. Accordingly, a central part of the study of physics has become the sequence of conducting experiments with physical objects, acquiring from those experiments insights that suggest other experiments, building from all of them an embracing theory to explain them, and testing the limits of the theory by exploring its predictions in still further experiments.

The pursuit of this process in our age, however, has become steadily more inferential. Increasingly the interest of physicists has been directed on the one hand toward submicroscopic physical objects and, on the other, toward enormous objects at great distances, whose behavior must be inferred from experiments on accessible objects of familiar size. Theories describing the inaccessible objects have been built as far as possible by extending to them the preexisting theories of accessible objects.

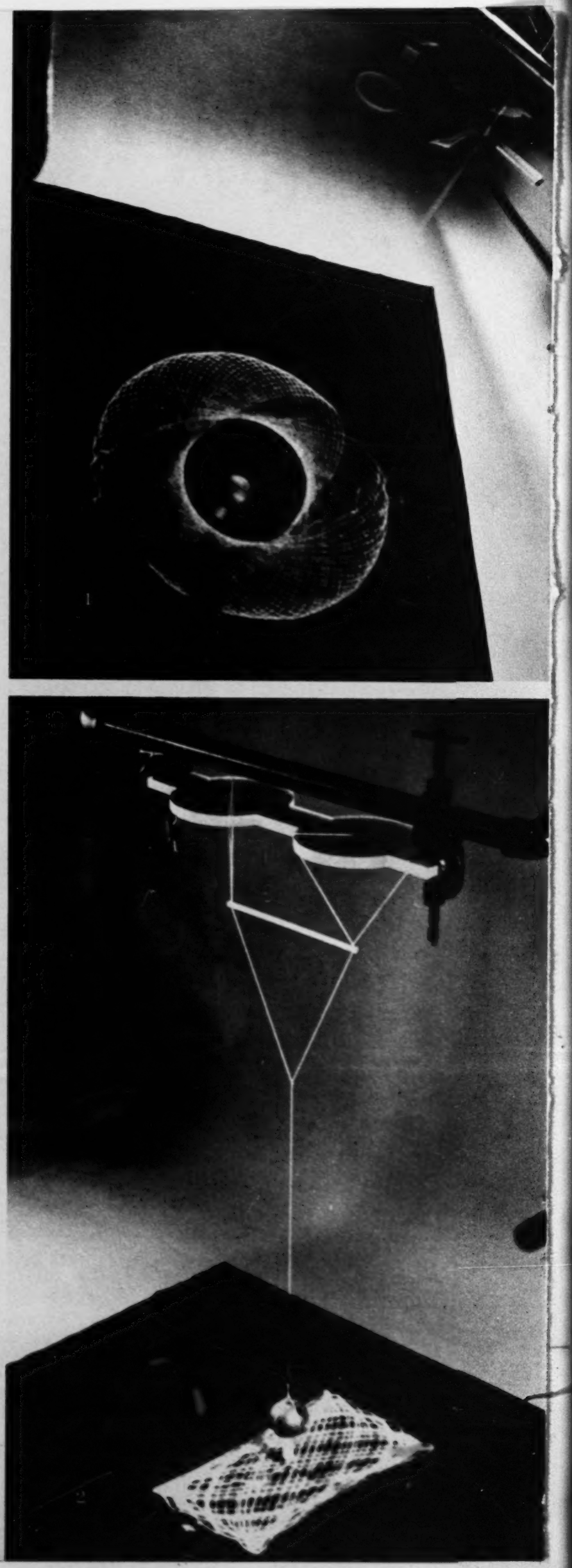
Thus a physics student today can instructively examine experiments on readily accessible objects for two reasons. In the first place, as in earlier times, such experiments have direct validity in displaying the behavior of the systems employed in them. In the second place, when they are suitably chosen, the experiments provide models or analogies portraying behavior that is at least tentatively presumable in physical systems not directly visible. These ideas are implemented in three distinct areas of experiments carried forward at Seattle.

Behavior of pendulums

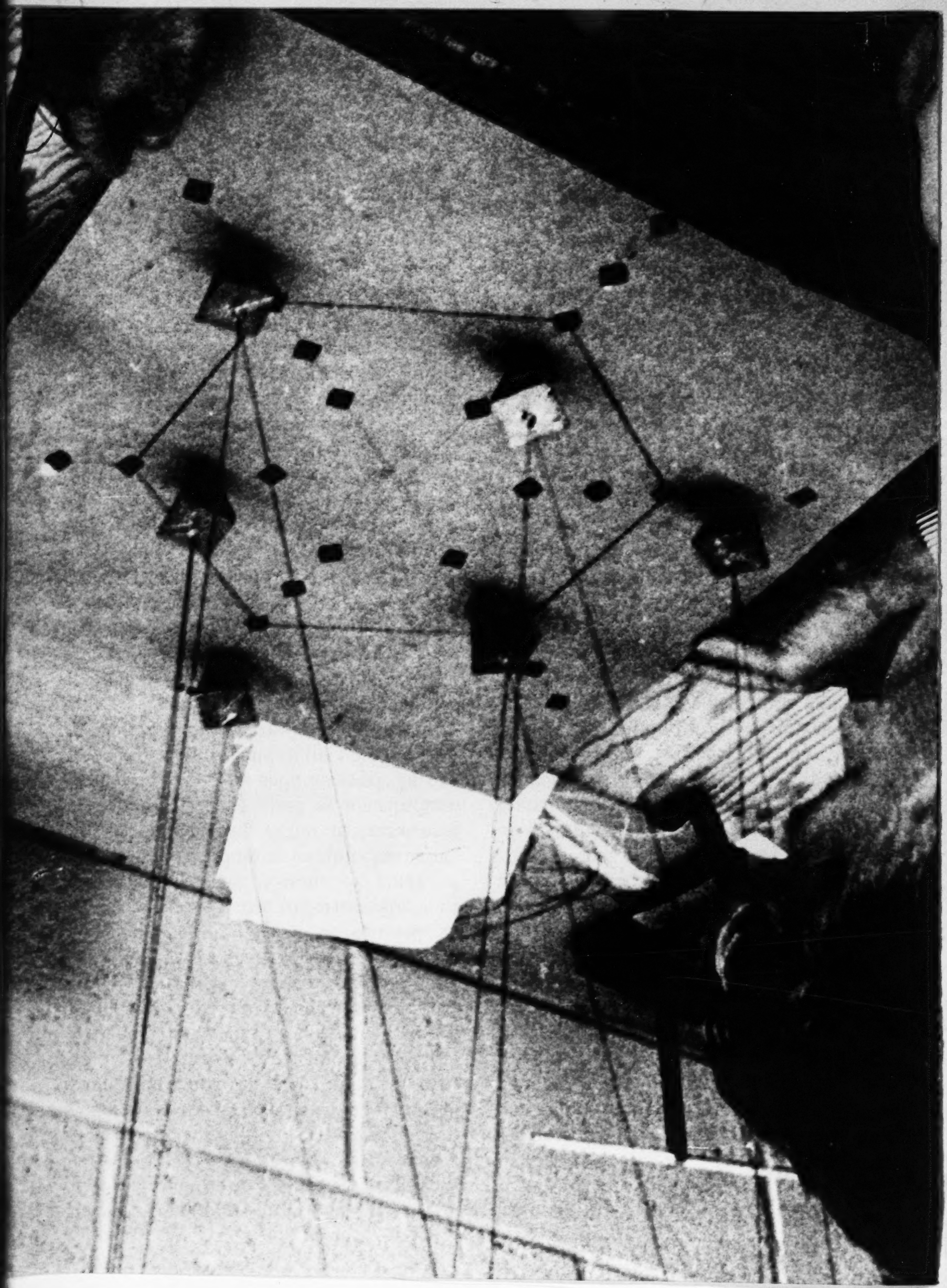
In the first area the experiments explore some of the classical mechanics of time-periodic systems by examining the behavior of pendulums. These experiments, designed by Judith Bregman, Richard Davisson, and Alan Holden, employ very simple tools — primarily fishing sinkers hung by fish line — but traverse a wide range of intellectual sophistication. They can be assembled into short sequences, usable separately at different levels of study and cumulative through several years.

Observing the behavior of the simple conical pendulum leads to the study of its damping, its precession, and the lifting of its degeneracy. The lifting leads to the discovery of two normal modes of motion and to the exploration of their dependence on the details of the lifting device, gradually making clear certain dynamical invariants in the system that have much broader application in physics.

The idea of orthogonality appears in two of its simplest meanings: (1) the motions in the two normal modes are geometrically perpendicular to each other, and (2) those two types of motion are dynamically



1. When a pendulum bob hangs freely from an isotropic support and swings in an elliptical path, the axes of the ellipse precess because the motion of a pendulum is not quite simple harmonic.
2. Suspending a pendulum from a saddle lifts the degeneracy which made possible the motion shown in Figure 1. The pendulum acquires two normal modes of motion that are perpendicular to each other and have different frequencies. Any more general motion can be regarded as a sum of the normal modes, and is confined to a rectangle whose sides are parallel to the directions of those modes. The upper parts of the saddle can be turned separately at any angles to the lower part, in order to show the dependence of the directions of the normal modes on the symmetry of the suspension, and to verify that the saddle always provides two mutually perpendicular normal modes, even though it may do so by executing complicated motions within itself.
3. A system of six pendulums coupled in a ring can be excited in any of its normal modes by using a template to establish a suitable initial condition.



uncoupled to each other. The use of a sand-dispensing pendulum displays graphically that any motion of the system is a superposition of motions in the two normal modes and hence is confined to a rectangle. A multiple saddle for suspending the pendulum dramatizes the facts (1) that the perpendicularity of the normal modes is independent of the suspension, and (2) that the orientation of the modes obeys the symmetry of the suspension.

Bifilar pendulums can be coupled, in readily variable ways, to form systems of coupled oscillators. Chains or rings of such coupled pendulums exhibit characteristic normal modes, either in transverse motion (coupled by ties) or longitudinal motion (coupled by soda straws). In one embodiment, six pendulums coupled in a ring exhibit two normal modes (of highest and lowest frequency) and two degenerate pairs of modes (of intermediate frequency), providing an analog for certain molecular vibrations.

In another embodiment a chain of twelve transversely coupled pendulums is driven in any one of its twelve modes at will by a massive pendulum of adjustable frequency. Driven from one end at a frequency higher than that of its highest mode, it displays an exponential envelope of amplitude decay with distance from the driven point. A one-dimensional analog to the "optical" and "acoustical" grouping of the modes of atomic vibration in a solid arises when either the mass of the pendulums or the strength of their couplings is alternated along the chain.

Pucks on an air table

The second area of experiment, developed by Harold Daw, employs plastic pucks, moving almost frictionlessly along a table, to study the kinetic and statistical properties of a system of many moving bodies agitated by confining walls and interacting by collision. The experiments provide a two-dimensional model for the picture of a gas as a large collection of moving particles interacting by forces of very short range, introduced by Daniel Bernouilli and elaborated since into the modern kinetic theory of gases. Daw's monograph on the puck experiment is described on page 8.

The heart of the apparatus is an "air table" which is perforated with tiny holes on a one-inch grid, supplied from beneath with air under pressure, and agitated by a crank shaft from a motor of variable speed. Pucks of several sizes permit study of systems containing "particles" of different masses and different cross-sections for collision. A fixed camera mounted high above the center of the table affords records of the motion for later analysis.

In one experiment sequence, pucks of uniform size are agitated and photographed with a short time exposure under a stroboscopic light. Analysis of such photographs provides a determination of the speed distribution of the pucks, for comparison with the theoretical distribution first derived by James Maxwell. Examination of such distributions under different degrees of agitation by the motor shows that all have the same Maxwellian shape, and are scaled by a single parameter.

The analysis can be extended to a determination of the collision frequency of the pucks with one another and with the walls, and the variation of these frequencies with the number of particles and the degree of agitation. Similar photographs taken when the table carries pucks of more than one size permit verification of the time-average equipartition of energy among the ingredients of the system.

In another experimental sequence, the path of an individual member of an assembly of interacting particles is traced by taking a time-exposed photograph of

the assembly when it contains one puck that bears a small light bulb and battery. The distribution of the lengths of its paths between collisions is found to be exponential, with the mean free path as the scaling parameter. On such a photograph the scattering angles can also be studied. By combining the distribution of scattering angles from the walls with the speed distribution and the frequency of collision with the walls, determined already, the pressure exerted by the two-dimensional "gas" on the walls can be calculated.

When the table is tilted, the study can be extended to an examination of the properties of the system in a uniform gravitational field. Records for analysis are conveniently made by photographing the assembly when it is covered by a sheet containing one slot, and moving the slot between exposures. A count of the pucks appearing under the slot, plotted against its position, yields the barometric distribution law. When one puck carries a light, time-exposed photographs show the parabolic paths of free flight.

Description of matter

The third area of experiment explores an unconventional approach to introductory physics, and is discussed in detail in the monograph described on page 9. Jack Soules, who wrote the monograph and who designed this sequence with assistance from Francis Haworth, describes his intention in this way:

When the purpose of the introductory course is to awaken the student's curiosity and interest in the natural phenomena around him, the study of matter is a good choice. Although some reference must be made to energy and to force, the treatment of these ideas can be *ad hoc* and largely intuitive.

A physics course whose purpose was the description of matter might introduce the ideas of volume, temperature and pressure at the outset. Then it would go on to develop such properties as viscosity, elasticity, conductivity, heat capacity, latent heat. The typical beginning student is usually unfamiliar with a great number of everyday phenomena. An effectively designed introductory course ought to make the phenomena literally accessible to him, as well as offer some mathematical and conceptual basis on which he can organize his observations. To be effective it should suggest models for the observed effects, but it should also encourage the student to invent models of his own.

In about 20 suggested experiments — some fully developed, others still to be perfected — students are introduced to many of the central physical properties of matter in bulk. For the most part the experiments are semi-quantitative. Emphasis is placed on the use of simple, commonplace

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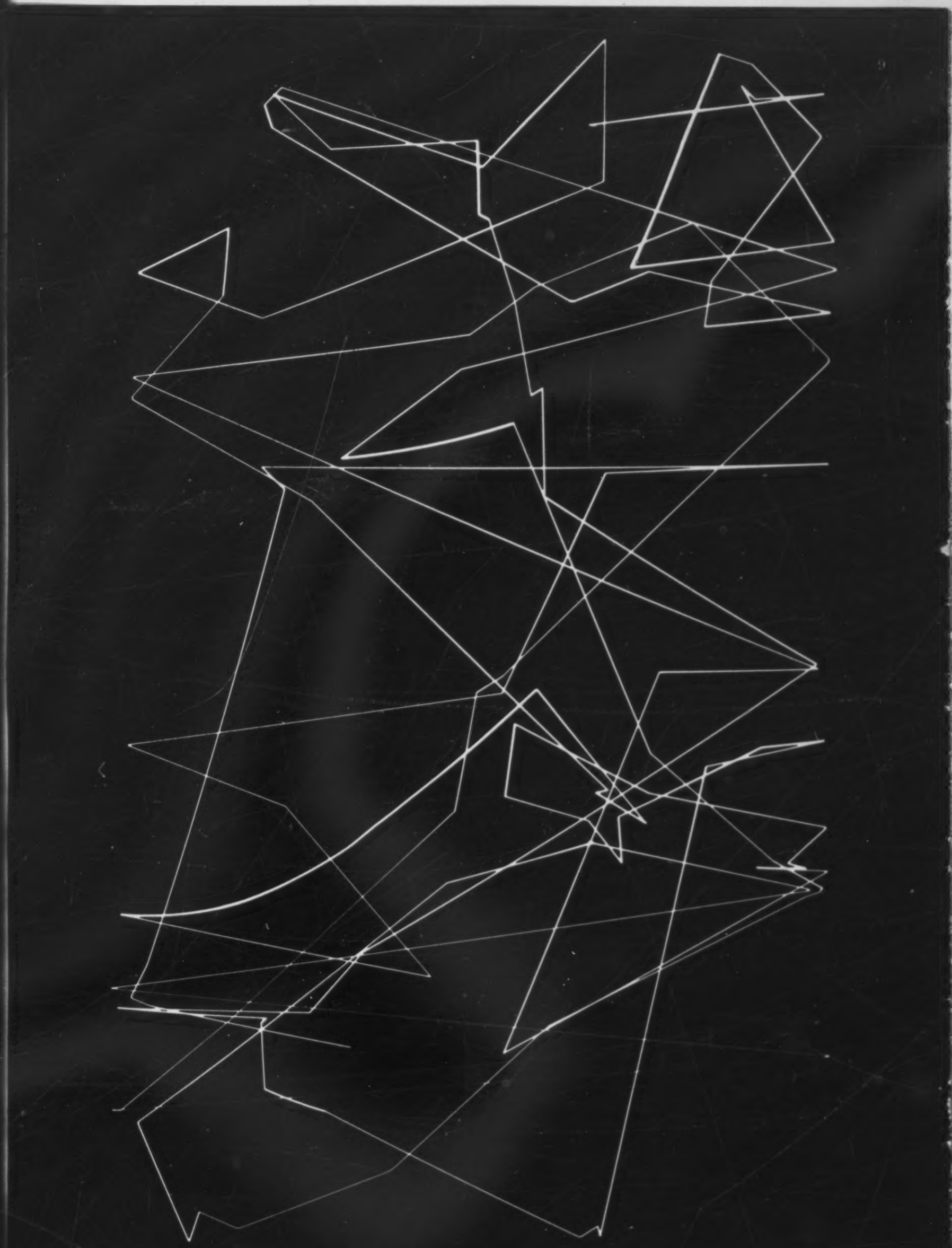
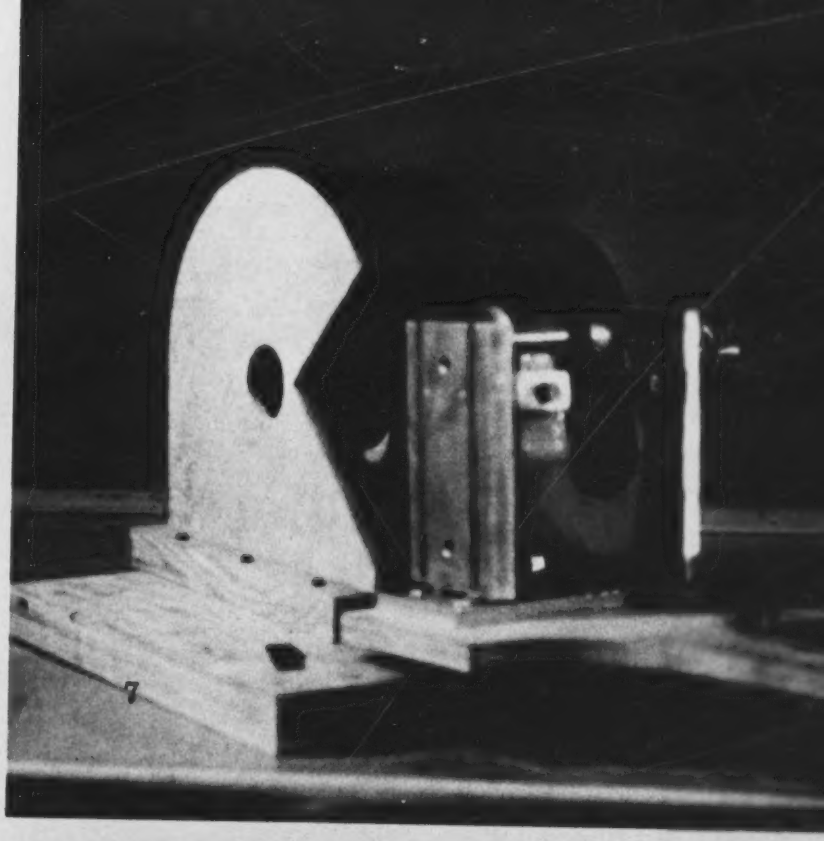
4. The apparatus for studying the kinetic behavior of many moving bodies, interacting by collision in a space confined by agitated walls, comprises a collection of Lucite discs on a perforated table supplied with air pressure from beneath. The table is pivoted about its center and agitated by a crank shaft at one corner. A stroboscopic lamp and a camera mounted high above the table enable records of the motion to be taken for later analysis.
5. A photograph of pucks on an air table, with short time exposure under a stroboscopic lamp, can be analyzed to yield the velocity distribution of the pucks.
6. A photograph with long time exposure of a collection of agitated pucks, of which one bears a small lamp bulb, provides a trace of the motion of a single member of the collection. By assuming that this puck is "typical," the trace can be analyzed to yield the free path distribution of the pucks and so to calculate a mean free path.



materials and apparatus, and a first acquaintance with rough examples of a variety of laboratory techniques commonly used in physical measurements, rather than on exact results. Such devices as screws and optical levers for measuring small displacements, and the use of null methods and difference methods, cultivate confidence in selecting or inventing suitable means for inquiring into physical properties.

In one experiment the vapor pressures of liquids are measured over a wide range of temperatures. A sample of liquid is placed in an aluminum cup and tightly covered by a thin rubber diaphragm. The cup is placed inside a bell jar connected to a vacuum pump, and is heated to the desired temperature. The pressure of air in the bell jar is reduced until the diaphragm begins to expand, and the pressure and temperature are then read with conventional equipment.

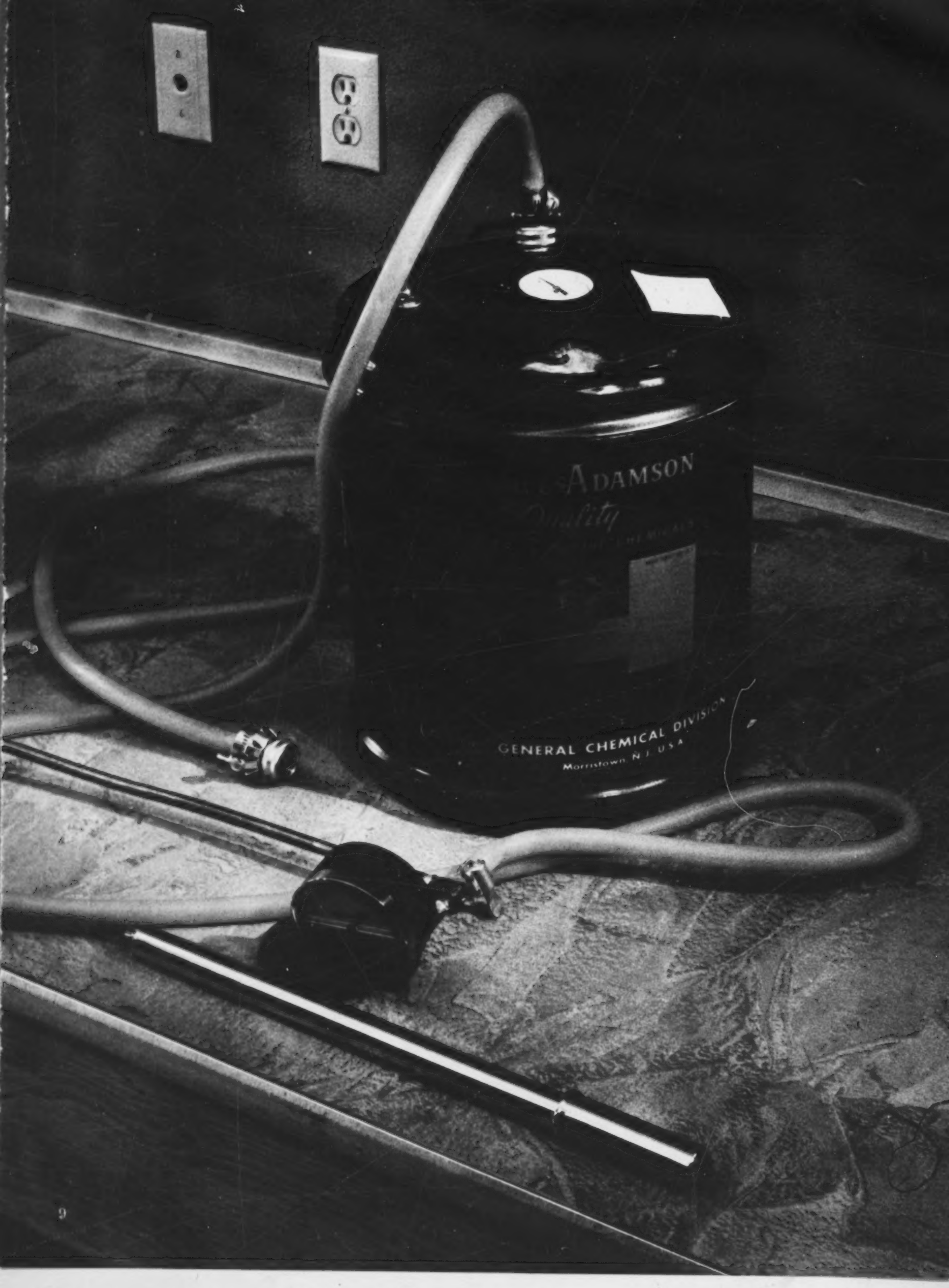
A second experiment, examining the laws of hydrostatics, uses a vertical pipe four inches in diameter and six feet high, with valves and pressure gauges at random intervals. Water pressures observed on the gauges are correlated with the positions of the gauges on the pipe. The information is checked by blowing air through a tube into the pipe and determining what air pressure is required for blowing a bubble at various depths.



7. A novel method for determining the mechanical equivalent of heat employs a flywheel with attached copper disc, and a magnetron magnet to bring the wheel to rest by inducing eddy currents in the disc.

8. A pipe four inches in diameter and six feet long, with valves and pressure gauges screwed into its wall, provides experimental means for examining hydrostatic principles.

9. With a bicycle pump the student pumps up this large can to a few pounds pressure. He introduces the air from the can into a standpipe, where it forms bubbles under water. The depth at which bubbles stop forming varies with the pressure, enabling the student to examine the relationship between pressure and depth in water.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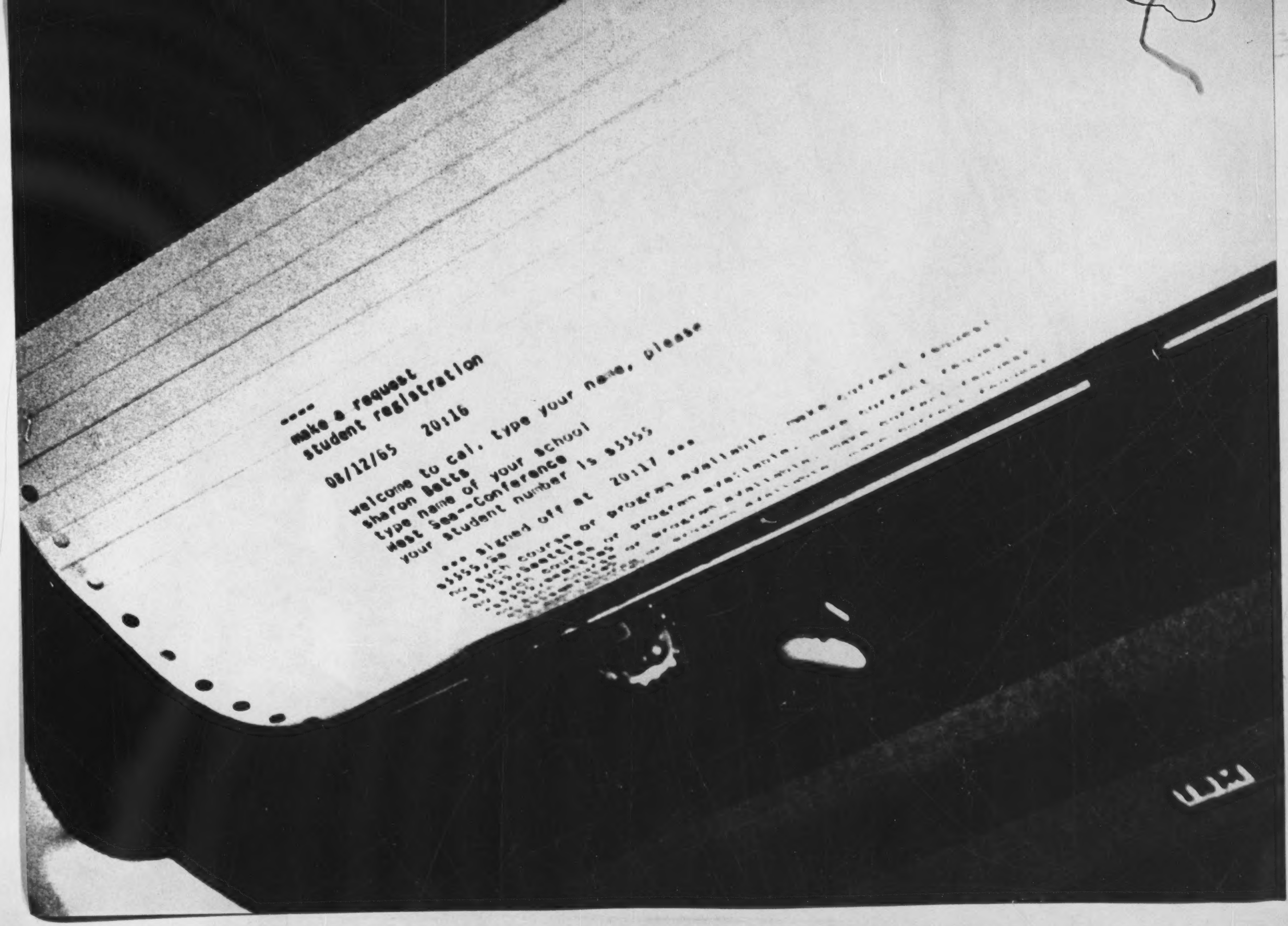
GENERAL CHEMICAL DIVISION
Morristown, N.J. U.S.A.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make a request
student registration
08/12/65 20:16
welcome to cal. type your name, please
sharon betts
type name of your school
host sea--Conference
your student number is 55555
... signed off at 20:17 ...

Computer-Assisted Instruction

Computers can assist instruction in a variety of ways. In the form explored at Seattle, the student participates in a tutorial dialogue with an instructional program stored in a computer. The thrust of the dialogue is determined by the educational objectives of the instructor.

The dialogue takes place through a two-way terminal, into which the student transmits his messages with a keyboard or other selection device, and from which he receives typed messages, tape-recorded messages, and slide displays. Because the computer can effect relatively complex, logical processing of messages, and condition the instructional sequence accordingly, this conversational mode appears to have considerable potential. It could, for example, supervise routine recitation and drill; it could also present problem-oriented remedial sequences requiring that the student correctly perform a hierarchy of tasks, a task consisting of a sequence of sub-tasks, or a task calling for a synthesis of disparate elements.*

The availability of real-time, terminal-oriented computer systems promises to soon make such instructional methods practical. The downward trend of computer costs suggests that they will become comparable, on a student-hour basis, to

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*The importance of this kind of help for physics instruction is dramatized by Professor J. A. Wheeler of Princeton University in a letter to E. D. Lambe.

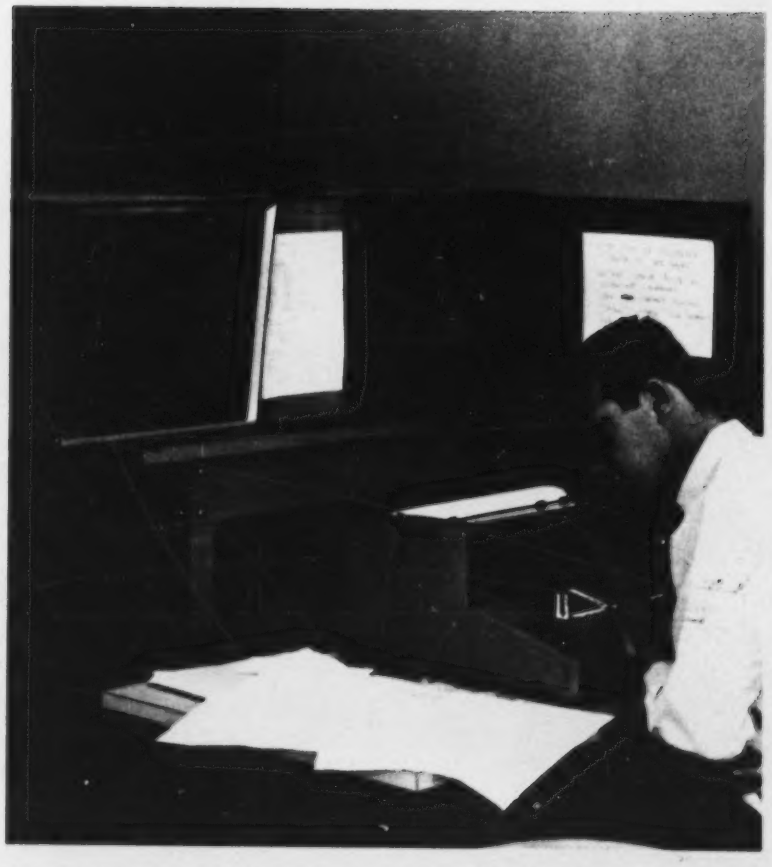
"Why so much more attrition in physics than, I believe, in other subjects? Is it not because each part of physics depends so much on the parts that have gone before? A student covers, say, 10 major topics in the first semester. If he is very good, he misses only 5 percent of each. When he has to answer at the end a question depending on all these topics, his chance to give a correct answer might be estimated, roughly and symbolically, as $(0.95)^{10} = 0.60$. If he is merely good (missing only 10 percent of each topic) — and rated as good in all his other subjects — then in physics he is terrible. His chance of giving a correct answer in the final examination, according to the same symbolic calculation, is only: $(0.90)^{10} = 0.35$. No wonder students who are good in other subjects often get quite discouraged in physics, and quit the field."

some present forms of college instruction. Experimentation with computer-assisted instruction (CAI) at Seattle was made possible by the collaboration of the IBM Corporation. By teleprocessing, CAI was conducted through two IBM 1050 terminals (and associated visual displays) connected by transcontinental telephone line to IBM 1440 and 7010 research computer systems in Yorktown Heights, New York.

As a medium of instructional interaction, the computer carries considerable promise. It also carries important limitations. Both have to do with the program functions that determine the processing of a freely constructed student response. Material can of course be presented at the terminal, but this is by and large an awkward way to read, and the terminal is an expensive device to tie up while a student thinks about something he is confronting for the first time. The computer, however, is uniquely able to categorize a student's response without automatically giving him the correct answer. Physics instruction commonly deals in problems which lead, after a series of steps, to numbers. Given a processing function that recognizes into which of several ranges a student's answer falls, the subsequent affirmative or corrective responses can be readily supplied to the program. The addition of a function which can identify one or more symbol strings in a response (e.g. "accel" or "accel" and "grav") results in a mechanism for recognizing an acceptable answer in most cases.

The man behind the machine

But it is clear that, though the mechanism exists, the physicist-teacher still has most of the hard work to do. For this is a dialogue, and the student has a right to expect a cogent and useful response from the man behind the machine. Providing him with one is far harder to do than it



looks, given the formalism of the response recognition. It is so difficult that it would not be tried at all but for the promise that, once done well, it need not be done again for every student, or every new student generation. As many teachers have noted, students are themselves enormously helpful in the process: their misconceptions and difficulties are fairly readily categorized and, with time and patience, remedied. The process is vastly enhanced by the computer's ability to record and compile such responses, and store the results. It is likely that once a course author understands what the machine can recognize, he will spend his time with trial students and card decks of statements, then send the results to be programmed.

A variety of instructional sequences were written and tried. Everett Hafner produced two sample units showing the use of the computer in examination — an area in which its ability to keep records and maintain neutrality combines with its ability to construct a number of examinations from a set of previously supplied component parts. The first of them (labeled "vel" under course Seattle 2 in

the 1440 CAI system) is a brief diagnostic exercise that seeks to discover, through a series of increasingly difficult questions, a student's understanding of the concept of instantaneous velocity.

Hafner's second unit (demo-2) is a simulated oral examination, attempting to probe, in about an hour, an advanced student's knowledge of a variety of topics: physical constants, rigid body motion, special relativity, fundamental interactions, and classes of particles.

William Blanpied programmed a sequence intended to assure the teacher that a student can interpret light polarization phenomena in terms of two photon states. This material is based on a section of the MIT Science Teaching Center presentation of quantum mechanics. Further development and student testing of this unit will be carried out at the Science Teaching Center.

Harry Prichett, Jack Ludwig, Richard Mould, and Edward Lambe developed a brief sequence on the concept of a world line. Their aim was a tutorial dialogue that would fully exploit the terminal's capabilities for control, for pacing, and for visual display. The slide projection screen is covered with a clear plastic overlay, on which the student draws the world line. As he goes along, he is asked to describe his graph through the typewriter. When an error is indicated, remedial slides appear.

Using the example of an object accelerated in an elevator, Arnold Arons constructed a program in which the student is led, step by step, to an understanding of "the sensation of weightlessness." This was a tutorial program, self-contained in that it aimed at the full presentation of this idea. Arons says of his impressions of the computer presented material:

> . . . The dialogue with the student had remarkable elements of flexibility — despite the obvious constraints. In particular, it was possible to inform the student of incorrect answers, give him hints, and allow several trials without revealing answers. Thus there seems to be considerable promise in this system of getting the student to originate his own response without putting initial steps before him or putting pre-canned words into his mouth. This, in turn, promises greater scope and flexibility . . .

The beginning section of the flow chart showing the multitrack nature of the question-response sequence for Arons' program is shown on page 32.

Geometrical optics unit

Most ambitious of the CAI projects was the unit on geometrical optics designed by T. R. Palfrey, R. L. Dough, and Victor Cook. A primary CAI objective at present is to try a significant sequence with a group of students who must take it seriously. Since there are few available terminals, any testing that involves an appreciable number of students will have to go on for a long time. Geometrical optics was chosen as a subject for the practical reason that it could be given to students at any time during an introductory course. Palfrey describes it this way:

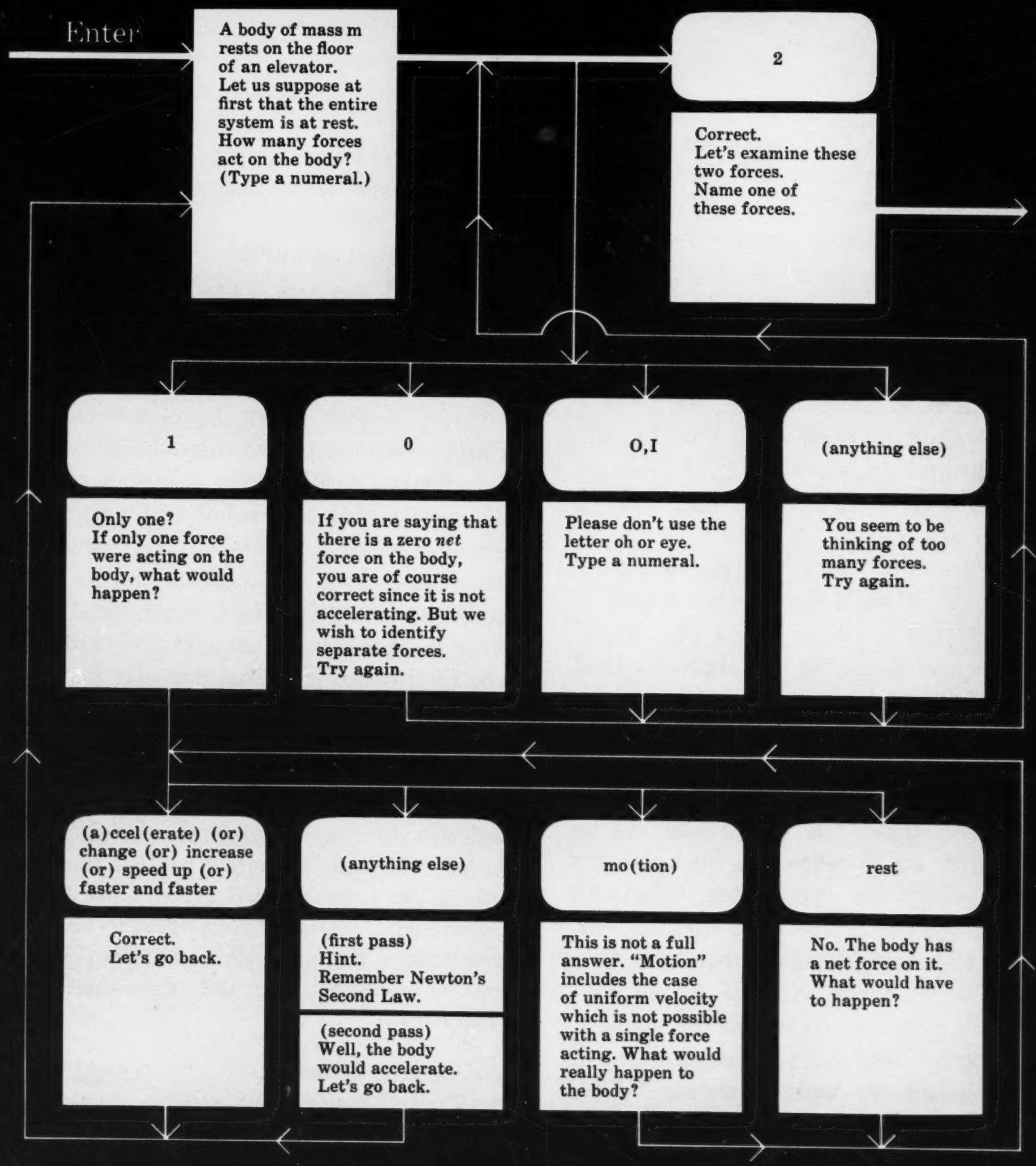
> The use of the material is designed to be optional for the student. He need not do the problems. If he does them, he may or may not use the help available to him for each problem on the terminal. The laboratory and laboratory help are similarly optional. No instructor will be available to the student for this material: there will be no lectures, no recitations, and no regularly scheduled laboratories on geometric optics. Only the examination is required.

Description of Materials.

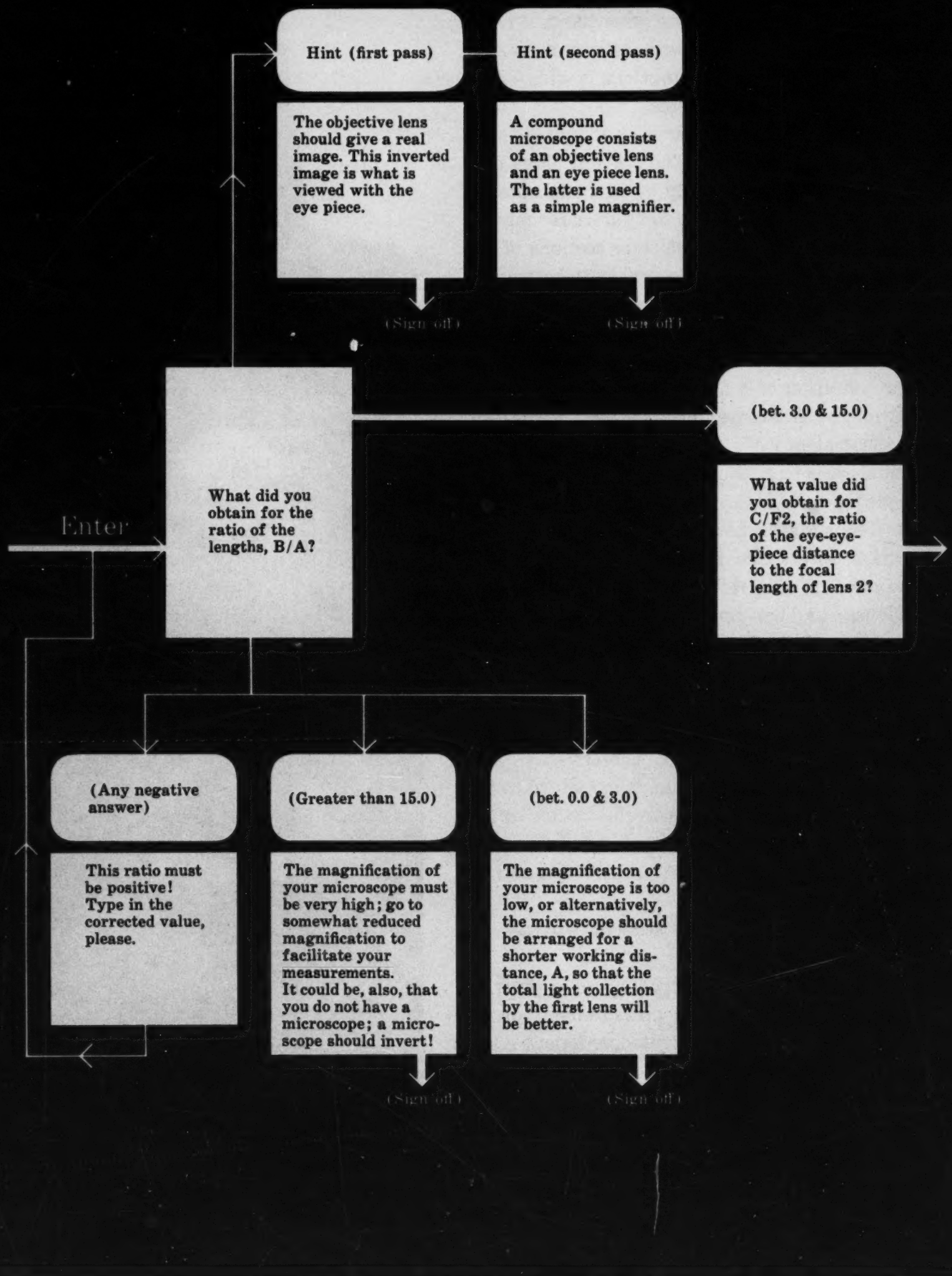
1. The text material suggested is Chapters 26 and 27 of Feynman, Vol. I.

2. The problem set has been constructed in the following manner: Problems have been collected from a variety of current texts and from several of the physicists at the conference. These have been sorted by subject matter and evaluated by a small panel in terms of their usefulness in the

Initial sequence on the concept of weightlessness


Enter
A body of mass m rests on the floor of an elevator. Let us suppose at first that the entire system is at rest. How many forces act on the body? (Type a numeral.)
2
Correct. Let's examine these two forces. Name one of these forces.
1
0
O,I
(anything else)
Only one? If only one force were acting on the body, what would happen?
If you are saying that there is a zero *net* force on the body, you are of course correct since it is not accelerating. But we wish to identify separate forces. Try again.
Please don't use the letter oh or eye. Type a numeral.
You seem to be thinking of too many forces. Try again.
(a)ccel(erate) (or) change (or) increase (or) speed up (or) faster and faster
(anything else)
mo(tion)
rest
Correct. Let's go back.
(first pass) Hint. Remember Newton's Second Law.
(second pass) Well, the body would accelerate. Let's go back.
This is not a full answer. "Motion" includes the case of uniform velocity which is not possible with a single force acting. What would really happen to the body?
No. The body has a net force on it. What would have to happen?

Initial sequence for an optics examination


Hint (first pass)
Hint (second pass)
The objective lens should give a real image. This inverted image is what is viewed with the eye piece.
A compound microscope consists of an objective lens and an eye piece lens. The latter is used as a simple magnifier.
(Sign off)
(Sign off)
Enter
What did you obtain for the ratio of the lengths, B/A?
(bet. 3.0 & 15.0)
What value did you obtain for C/F2, the ratio of the eye-eye-piece distance to the focal length of lens 2?
(Any negative answer)
(Greater than 15.0)
(bet. 0.0 & 3.0)
This ratio must be positive! Type in the corrected value, please.
The magnification of your microscope must be very high; go to somewhat reduced magnification to facilitate your measurements. It could be, also, that you do not have a microscope; a microscope should invert!
The magnification of your microscope is too low, or alternatively, the microscope should be arranged for a shorter working distance, A, so that the total light collection by the first lens will be better.
(Sign off)
(Sign off)

context of the self-taught unit and the computer-assistance feature. Plug-in problems have been eliminated, the ideas in them being incorporated into more physical, and hence often more complex, problems. With the availability of the computer assistance it is practical to include several concepts in each problem. On the other hand, it is not expedient to construct problems where the variety of correct answers or explanations is wide — the so-called open-ended problems.

3. The computer assistance on the problem set is arranged by problem: The student signs onto the computer, requests help by problem number, and is interrogated by the computer. He may be asked if he has read appropriate sections of the text in connection with the problem; he may be asked about definitions, sign conventions, or his results for parts of the problem. The terminal will normally provide help in the following forms: by presentation of a slide sketch of the physical situation, by reference to the text, by suggesting that the student work another problem first, or, in unusual cases (e.g., diopters to m^{-1}), by supplying a needed piece of information.

4. The subjects treated in the laboratory instruction sheets are reflection from plane and spherical surfaces, refraction at plane surfaces, thin lenses, and lens combinations.

5. Computer assistance on the laboratory is designed to help students perform the experiments, should they feel they need help, and to reinforce them, should they need assurance that what they have done is indeed correct.

6. The sample examination is presented to the students to make clear to them the nature of the examination over geometric optics, in particular the computer-controlled portion of the examination.

7. The examination the student will take is divided into two parts:

Part I involves the construction of a piece of optical apparatus and the measurement of its properties. This part is presented as follows: The student is given a kit of lenses, etc., and an optical bench. He is told to build an instrument that meets certain specifications (e.g., a non-inverting "projector" consisting of two lenses, such that the object-to-projected-image distance be the length of the optical bench, and the object-to-second-lens

distance be as short as possible). He is asked to measure properties of the finished device (distances, focal lengths, magnifications, etc.). When he has measured the suggested parameters, he signs onto the terminal, and answers questions about the device he has built. The terminal may accept his answers, or may decide that his measurements were too sloppy, or that his device could not have worked as specified. Instructions and hints from the terminals then guide the student (at a cost in examination score) toward a good design. When the design and measurements meet the standards required, the student is given Part II of the examination.

Part II consists of one or two questions designed to find out if the student either understands the functioning of the device he has just finished building, or can figure it out. These are ordinary paper-and-pencil problems. The possibility exists that the student could report his results on Part II to the terminal, which could then grade his result.

Several features of the examination need to be pointed out. First, it is designed to divide emphasis among text, problems, and laboratory. Second, the laboratory part is designed in such a way that the student is expected to apply his knowledge partly empirically — he will not be expected beforehand to know much, if anything, about optical instruments — and so to use his knowledge to obtain new knowledge. Third, since the student spends most of his time making measurements and calculations, his use of the terminal during the examination is minimal (one or a few 5-to-10-minute bursts) so that several students could be examined simultaneously with only one terminal and little waiting.

A section of the logical flow chart from one of the optics examinations is shown on page 33.

The optics unit was revised and tested at the State University of New York at Stony Brook, where, during the spring semester, one or two terminals were available to 220 students in Physics 102. The unit replaced the four lab sessions in which the same material was previously taught.

Promising though it is, the physics prepared for CAI is still too fragmentary to receive realistic trial and evaluation. For that to be done, students will have to receive computer assistance on a continuing basis, as a crucial part of regularly scheduled instruction. The preparation and testing of appropriate material will make severe demands on the time of many teaching physicists; but there is no other way to validly assess the contributions of this new instructional medium.

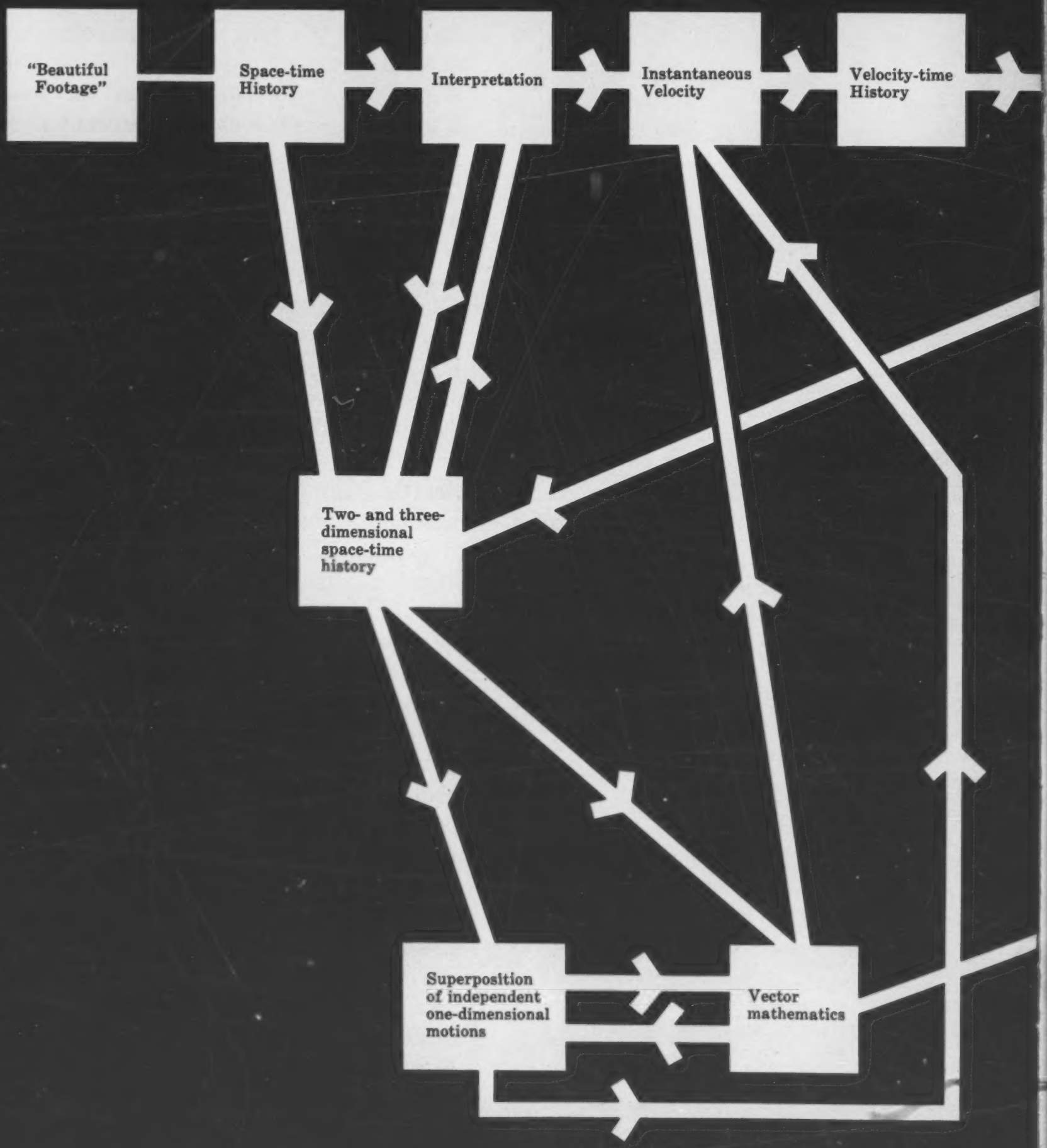
Designing a Unit of Instruction

A dilemma faced by anyone seriously interested in experimenting with new instructional forms has to do with the problem of exploiting talents outside his field of professional competence. Obviously any effort to improve the teaching of physics must depend chiefly on physicists. Yet the same knowledge and experience that can make a physicist impatient with present pedagogy may also render him unable to do anything about it in a fresh way. Conferee after conferee, in conference after conference, has argued the necessity of "breaking out of conventional molds," implying that the limitations of commonplace teaching patterns constitute a sort of methodological imprisonment. Perhaps, as with successful prison breaks in the movies, the secret ingredient is a friend on the outside.

With something like that in mind, the Seattle planning called for a substantial number of non-physicists as full-time participants. These included film makers, graphic artists, animators, writers and editors; but in the Seattle context these designations reflect background rather than job assignment, and the group can be broadly defined as "designers." They were not on hand to manufacture visual aids, edit or illustrate manuscripts, or produce films on order. Their function was to use their wide range of skills, without preconceived attitudes toward any particular medium of expression, to help find new terms for expressing the ideas of physics clearly and imaginatively.

The distinction is important. It is relatively easy to decide to make a film or write a monograph or set up a demonstration. But it is unlikely that any such isolated decisions will lead to truly new pedagogy, however excellent the individual products. A more fruitful approach might be to take a troublesome but easily defined unit of instruction and, within the constraints of college and university curricula, try to re-

Motion flow chart



design its presentation totally, deciding on the basis of each medium's inherent capabilities what share of the pedagogical load it can best carry.

Or so the "designers" seemed to be saying.

Some hard questions arose. Could a unit of instruction actually be "designed" like an industrial corporation's design program, effecting the integration of product engineering, graphics, exhibitions, ergonomics, etc.? Could physicists and designers collaborate effectively with such a goal in mind? Could a designer possibly participate creatively without himself having a considerable background in physics? If he could and did, wasn't the substance in jeopardy? If he could not, were there practical ways of providing him with the requisite background?

Subject: elementary kinematics

With such questions in mind, a small but intense experiment was launched in the final weeks of the conference. Four physicists and three designers set out to expose elementary kinematics to one week of design analysis. The physicists were Arnold Arons, Harold Daw, Everett Hafner, and Noah Sherman, who acted as chairman. The designers were Maurice Constant, Richard Hartzell, John Neuhart. Harry Woolf, an historian of science, sat in frequently. Nancy Tobey, an apprentice designer, assisted.

The group tried to outline a sequence of steps that would begin by introducing students to the concept of motion and lead from there to a final understanding of acceleration. The flow diagram at left is a graphic representation of their approach. Except for "Beautiful Footage" (intended to permit the student to scan the landscape of ideas before he encounters them singly), the top sequence is easily identified as the route common to most physics courses.

The group tried to devise ways of improving the route by design; they also reconsidered linkages, and suggested the alternate routes shown on the diagram. One of these, for example, would explore the superpositions of independent one-dimensional motions before entering the concept of velocity.

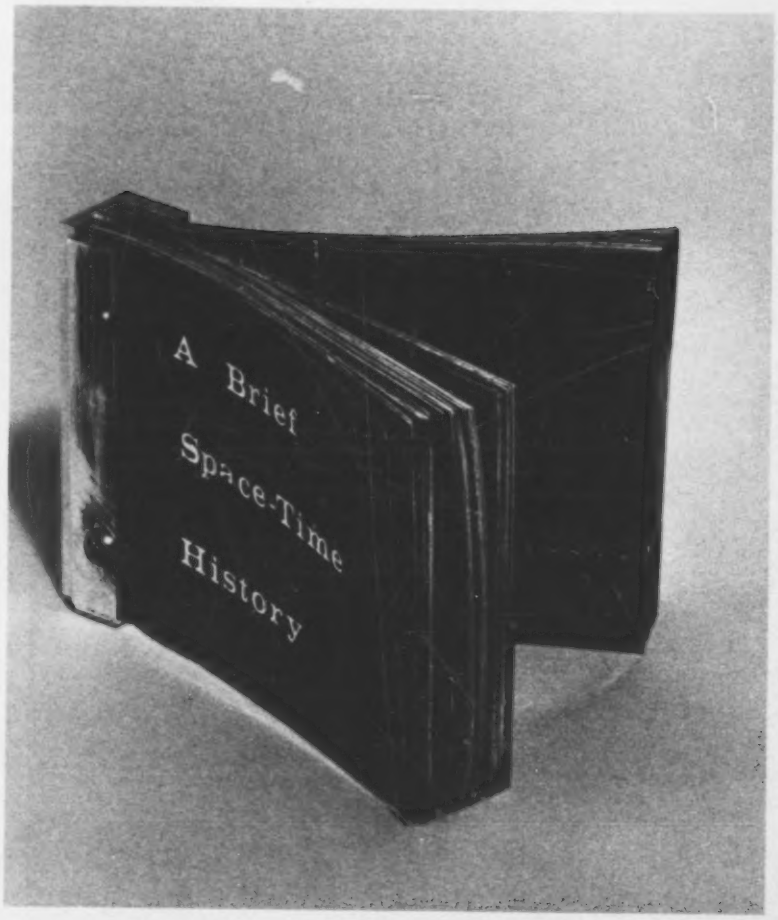
"Beautiful Footage" is of course a wish rather than an achievement, although the group did tentatively outline a motion film. Such footage (as opposed to a complete movie) was envisioned by one of the physicists as "beautiful pictures of motion, emphasizing both the vast range of phenomena and the vast range of rates of change. . . ." It would introduce the subject, "capitalizing on a rich and vivid visual content to lead the student intuitively and directly to such initial abstractions as 'particle,' 'point mass,' 'trajectory,' and to the representation of motions by position-time diagrams. One might thus avoid starting with long verbal expositions and definitions, get the students to a first level of comprehension . . . and spiral back to sharper articulation or verbal description at some strategic later moment."

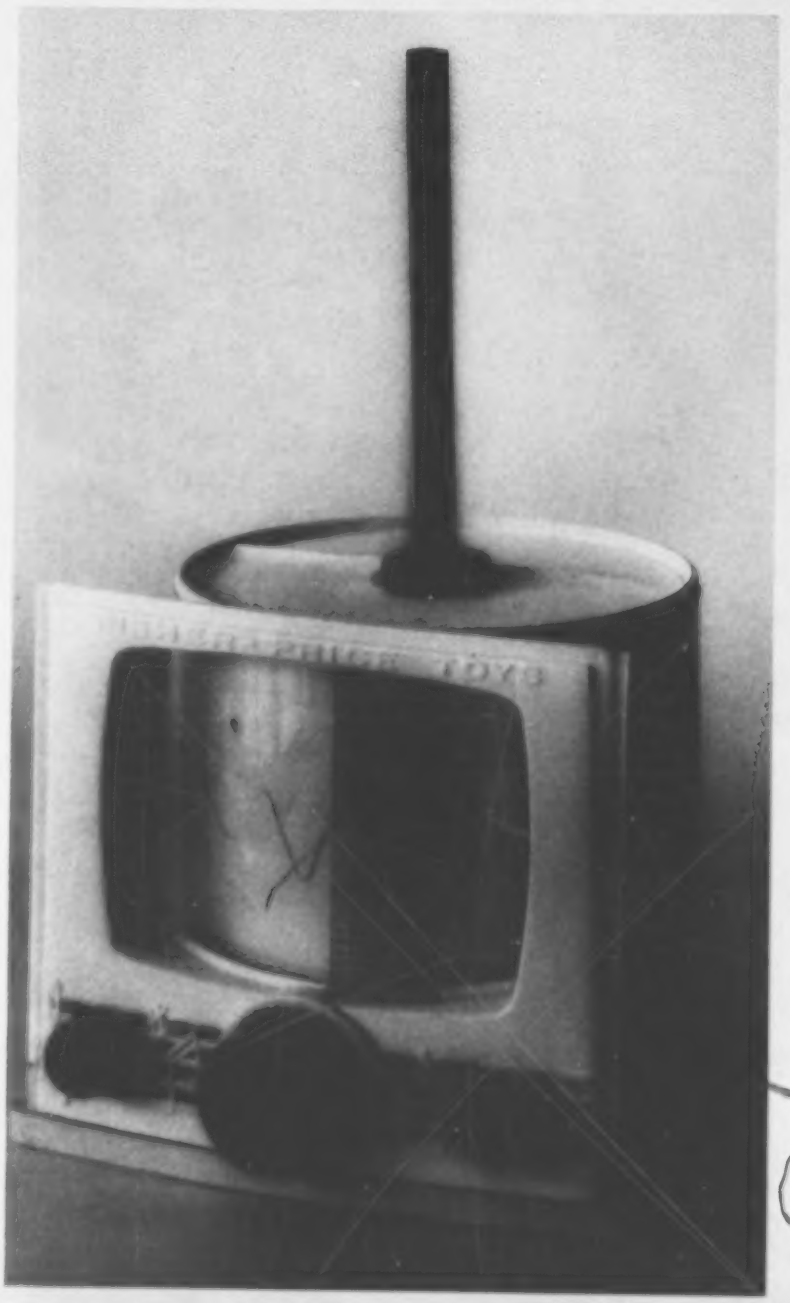
Notions and gadgets

In addition to imaginary footage, two film proposals came out of the motion group: an introduction to space-time histories; and *Galileo*—a filmic re-creation of the dramatic importance of his work and the intellectual climate in which he did it.

Other ideas included:

Hafnergrams. These are named after Everett Hafner, who devised them. Ordinarily physics courses rely heavily on algebraic relations to demonstrate coherence and construct proofs. Hafner sees the possibility of an equivalent graphical language for kinematics — one which would be wholly visual, dispensing with both words and mathematics, making kine-





matics understandable to students through visual symbols alone.

Gadgets. A number of these were developed, all of them intended to illustrate the meaning of a space-time diagram.

1. Flip pad. This neat device is based on the principle of the old penny arcade flickers. A stack of cards is bound together; each bears a picture of a man and a graph of his world line. As the student flips the cards, the man walks back and forth while his world line is traced out on the graph.

2. Kymograph. A roll of 3″ cash register tape is drawn by a clock motor over a flat writing surface, and a ruler is mounted across the flattened section of tape. A pencil which is moved along the ruler draws the world line of its point on the moving tape.

3. Tanks. A tank is filled with a viscous transparent liquid (Karo syrup). If the tank's axis is considered the time axis, with time increasing in the downward sense, and its bottom a two-dimensional space (x-y axes), then an object moving at the bottom has a world line spiraling above it and recording the object's history. If the object emits small bubbles of air, each bubble will rise slowly to the top, and the resulting trail of bubbles will represent the world line of the object moving in a two-dimensional (x-y) plane.

Dictionaries. Two ideas here. First, a dictionary based on the accordion or bellows fold. Opened as a book, it is simply a list of the terms used in kinematics; unfolded fully, it shows the relationship between those terms. The second notion is that of a filmclip dictionary, illustrating and defining various types of motion in 3-D stereo computer-animated film.

Motion Room. A room which can be tipped, rotated, raised and lowered, and given uniform or accelerated translation. The room would be equipped with back-illuminated screens for walls and ceiling, and films would project scenes simulating all types of motion. It would be possible to study motion in a non-inertial frame of reference, or to show (when the room is tipped) how objects behave in a gravitational field that does not point "down." With only the simplest of accelerometers students could measure simulated acceleration time sequences and obtain velocity and position data from these.

Those are the most describable products of the group's activities, but of course they are merely suggestive and fragmentary. Arnold Arons probably expressed the sense of the meeting when he reported, "I felt that our contacts with the designers and film makers were stimulating, interesting and promising, but nothing has yet emerged to demonstrate that this contact can really result in the production of some first class teaching materials." The week's experiment surely was worthwhile less for any materials, or even pedagogical ideas, it produced than as the first stage of a model for similar task forces, working for much longer periods of time, under more favorable conditions generally. The design process is formidable under the best of circumstances; but at least something was learned about what those circumstances might be, and about the mix of physicists and designers most likely to be able to take advantage of them.

Toward New Solutions

The Seattle conference dramatized a qualitative change in the way many concerned physicists approach undergraduate physics instruction. Essentially that change consists of a shift from an emphasis on special content for special student audiences, to an emphasis on producing a variety of materials that can be usefully integrated into existing curricula.

In 1962 the Second Ann Arbor Conference on Undergraduate Physics Curricula (cf. *Am. J. Phys.* **31**, 328, 1963) sought to distinguish between two kinds of undergraduate instruction. One kind (called "R," for research) was for students intending to go on to the PhD in physics; the other (called "S," for synthesis) was for students whose professional needs go beyond the introductory course but stop short of the doctoral degree.

The curricular requirements of the second group were the primary concern of a conference held at Princeton in 1963. Much of the discussion at that conference dealt with the problem of achieving an optimum balance between synthesis on the one hand and detailed mathematical analysis on the other. Another subject of heavy discussion was the creation of curricular structures that would, for the sake of flexibility, offer many more logical entrances and exits than is now common. Working groups at the conference prepared outlines of three such curricula (cf. *Am. J. Phys.* **32**, 491, 1964).

It became clear, however, that even the most profound discussions and the most thoughtfully prepared curricular outlines could not in themselves lead to pedagogical solutions. What was necessarily missing, but urgently needed, were specific examples of the new approaches considered in the discussions, and the new material components implied by the curricular outlines.

The search for these examples led to

(and leads from) Seattle. During the summer of 1964 a dozen or so physicists met at Aspen, Colorado to work on preliminary versions of text materials, and to discuss the possibilities of the "S" curriculum.

The elusive "S"

"S" had been advanced at a time when the problem of reaching a new student audience had seemed to call for special course content; and considerable energy had been spent on defining that audience and describing curricula appropriate to it. But "S," which was recognized from the first to be easier said than done, turned out not to be much easier said. "S" students were thought to need physics, or to *want* physics, or both. But they were identified almost wholly in terms of negative characteristics: either they were not taking physics courses, or they were taking introductory courses but going no further. These categories made it possible to talk about "S" students, but not to address their needs.

And that was precisely the difficulty in writing samples at Aspen. Since the anticipated audience was too diverse to be addressed as a homogeneous unit, what was needed was a collection of diverse materials. Such materials seemed almost impossible to create, however, without more information than was available about the level of preparation that an author could expect of his readers. Perhaps the solution lay in a written presentation that could be substantially independent of what had gone before and what was to come after. The multi-level monograph (page 5) was conceived in response to this idea.

The specific examples to be produced at Seattle, then, were, and were understood to be, written examples. But it was also understood that writing would not be enough. Other kinds of models were required, and with the urgent demand for these came the realization that the physics community alone could not create them.

That is why designers, film makers, and professional writers were included in the Seattle project. But although their presence was from the beginning intended to represent more than just a collection of special technical skills, it was not easy to see how much more than that it *could* represent. The aim was to use design as a significant approach rather than merely a handy tool; but neither physicist nor designer had experience in taking a design approach to physics instruction.

Seattle provided some such experience — at least enough of it to make participants aware of how much more was needed, and how urgently. It was the conviction that instructional design had not been adequately explored that led to the *ad hoc* design group whose one-week session is described on page 37.

The search for models

That design group is itself illustrative of the search for working models that has, since the Princeton conference, characterized these efforts to radically improve undergraduate instruction. The desired models are not patterns to be followed slavishly, or necessarily to be followed at all. Rather they are working models — functioning specific examples that can be pressed into service, tested, manipulated, and adjusted. Such models could enable an instructor to vary the architecture of his course without having first to get existing structures out of the way.

The Seattle conference was concerned with creating models in another sense as well, namely models of the mechanics of *making* instructional models. The operation of the instruction-unit design group, for example, reveals the central paradox of instructional design. All other things being equal, it is desirable that the de-

signer be introduced into the problem-solving situation at the earliest possible stage, before any decisions have been made about presentation. Yet, since all other things (e.g. the designer's understanding of physics) are demonstrably *not* equal, this is extremely difficult to do.

But there is abundant evidence that something like it must be done. And there is, from the Seattle experience, enough indication of how it might be done to encourage a sustained investigation of three lines of collaborative endeavor.

The first is the kind of intense collaboration between physicist and artist that led to the development of the symmetry film (page 14). In that case the non-physicist was a gifted film animator; in other cases he might be a sculptor or a writer or an illustrator.

The second one is a long-term project of the sort that was tried for a week at Seattle: a team of carefully chosen physicists and designers working jointly to produce a self-contained unit of instruction.

The third is closely related to the second, differing from it only circumstantially. There are already in existence professional design groups that approach problems in a manner similar to that of the Seattle group. As an alternative to setting up a design team from scratch, so to speak, an existing professional group could be retained to work closely with physicists.

As has been pointed out elsewhere in this report, writing was the central task at Seattle. And writing may always be central to the long-range task of bringing fresh resources to the support of physics teaching. But the new solutions that are needed require as well the sensitive utilization of disciplines and techniques not conventionally associated either with teaching or with physics. They require continued effort toward physics instruction by design.

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Photographs of the Conference were taken by Harry Prichett, Leonard Eisenbud, and David Eisenbud. People in the pictures are: page 2, Maurice Constant; page 4, Judith Bregman; page 6, Edwin Uehling; page 8, Leonard Eisenbud; page 10, George Michael; page 12, Stephen Wigler and Nancy Tobey; page 13, John Neuhart; page 18, Alan Holden; page 26, Jack Soules; page 30, Michael Brady; page 42, Maurice Constant; back end paper, Arnold Arons.

Participants

Arnold B. Arons
Professor of Physics
Amherst College
Amherst, Massachusetts

Gordon Ashby
Designer
84 Vandewatter Street
San Francisco, California

Nandor Balazs
Professor of Physics
State University of New York
at Stony Brook
Stony Brook, New York

William A. Blanpied
Assistant Professor of Physics
Yale University
New Haven, Connecticut

Alfred M. Bork
Associate Professor of Physics
Reed College
Portland, Oregon

Wayne A. Bowers
Professor of Physics
University of North Carolina
Chapel Hill, North Carolina

Judith Bregman
Associate Professor of Physics
Polytechnic Institute of Brooklyn
Brooklyn, New York

Donald R. Brown
Professor of Psychology
Center for Research
in Learning and Teaching
University of Michigan
Ann Arbor, Michigan

Laurie M. Brown
Professor of Physics
Northwestern University
Evanston, Illinois

Ralph Caplan
Writer
440 West End Avenue
New York, New York

Maurice Constant
Assistant Professor of Design
University of Waterloo
Waterloo, Ontario

Victor Cook
Assistant Professor of Physics
University of Washington
Seattle, Washington

Robert M. Cotts
Associate Professor of Physics
Cornell University
Ithaca, New York

Robert K. Cralle
Physicist
Lawrence Radiation Laboratory
Livermore, California

J. Gregory Dash
Professor of Physics
University of Washington
Seattle, Washington

Richard J. Davisson
Physicist
University of Washington
Seattle, Washington

Harold A. Daw
Professor of Physics
New Mexico State University
University Park, New Mexico

Robert W. Detenbeck
Associate Professor of Physics
University of Maryland
College Park, Maryland

Robert L. Dough
Assistant Professor of Physics
North Carolina State University
Raleigh, North Carolina

Leonard Eisenbud
Professor of Physics
State University of New York
at Stony Brook
Stony Brook, New York

James B. Gerhart
Professor of Physics
University of Washington
Seattle, Washington

Everett M. Hafner
Associate Professor of Physics
University of Rochester
Rochester, New York

Richard F. Hartzell
Executive Producer
Instructional Resources Center
State University of New York
at Stony Brook
Stony Brook, New York

Francis Haworth
Lecturer in Physics
University of Washington
Seattle, Washington

Ernest M. Henley
Professor of Physics
University of Washington
Seattle, Washington

Robert Hermann
Professor of Mathematics
Northwestern University
Evanston, Illinois

Arthur Herschman
Editor, *Physical Review*
Brookhaven National Laboratory
Upton, New York

Alan N. Holden
Physicist
Bell Telephone Laboratories
Murray Hill, New Jersey

Boris Jacobsohn
Professor of Physics
University of Washington
Seattle, Washington

E. Leonard Jossem
Professor of Physics
Ohio State University
Columbus, Ohio

Edward D. Lambe
Professor of Physics
State University of New York
at Stony Brook
Stony Brook, New York

Jeremy Lepard
Designer
5831 Sunset Blvd.
Los Angeles, California

Noah Lerman
Lecturer in Physics
University of California
at Berkeley
Berkeley, California

Jack Ludwig
Professor of English
State University of New York
at Stony Brook
Stony Brook, New York

Richard T. Mara
Professor of Physics
Gettysburg College
Gettysburg, Pennsylvania

Richard C. Meyer
Film Maker
13929 Chandler Blvd.
Van Nuys, California

George A. Michael
Physicist
Lawrence Radiation Laboratory
Livermore, California

Richard A. Mould
Associate Professor of Physics
State University of New York
at Stony Brook
Stony Brook, New York

Seth Neddermeyer
Professor of Physics
University of Washington
Seattle, Washington

John Neuhart
Designer
1728 Monterey Boulevard
Hermosa Beach, California

Rudi Nussbaum
Associate Professor of Physics
Portland State College
Portland, Oregon

Thomas R. Palfrey, Jr.
Professor of Physics
Purdue University
Lafayette, Indiana

Norman Pearlman
Associate Professor of Physics
Purdue University
Lafayette, Indiana

Melba Phillips
Professor of Physics
University of Chicago
Chicago, Illinois

Susan Presswood
Physicist
Commission on College Physics
Physics and Astronomy Building
University of Michigan
Ann Arbor, Michigan

Harry Prichett
Film Maker
Norfield Road
Weston, Connecticut

Marc H. Ross
Professor of Physics
University of Michigan
Ann Arbor, Michigan

Noah Sherman
Associate Professor of Physics
University of Michigan
Ann Arbor, Michigan

Jack A. Soules
Professor of Physics
New Mexico State University
University Park, New Mexico

Philip Stapp
Film Maker
54 East 81st Street
New York, New York

James Strickland
Physicist
Educational Services, Inc.
47 Galen Street
Watertown, Massachusetts

George L. Trigg
Assistant Editor
Physicial Review Letters
Brookhaven National Laboratory
Upton, New York

Edwin A. Uehling
Professor of Physics
University of Washington
Seattle, Washington

Harry Woolf
Professor of the History of Science
The Johns Hopkins University
Baltimore, Maryland

Consultants

Edward N. Adams, Jr.
Director of
Computer-Assisted Instruction
IBM Corporation
Yorktown Heights, New York

Ronald Geballe
Professor of Physics
University of Washington
Seattle, Washington

George Geis
Psychologist
Center for Research
in Learning and Teaching
University of Michigan
Ann Arbor, Michigan

Edward Gerjuoy
Professor of Physics
University of Pittsburgh
Pittsburgh, Pennsylvania

James Grunbaum
Designer
RFD 3
Old Lyme, Connecticut

Walter C. Michels
Professor of Physics
Bryn Mawr College
Bryn Mawr, Pennsylvania

Lyman G. Parratt
Professor of Physics
Cornell University
Ithaca, New York

Statton Rice
Film Consultant
66 S. Main Avenue
Albany, New York

Matthew Sands
Associate Director
Stanford Linear Accelerator Center
Stanford University
Stanford, California

George M. Volkoff
Professor of Physics
University of British Columbia
Vancouver, British Columbia

John Whitney
Film Maker
9134 Sunset Blvd.
Hollywood, California

Lawrence Wilets
Professor of Physics
University of Washington
Seattle, Washington

Jay F. Wilson
Managing Editor
D. Van Nostrand Co., Inc.
120 Alexander Street
Princeton, New Jersey

Karl L. Zinn
Psychologist
Center for Research
in Learning and Teaching
University of Michigan
Ann Arbor, Michigan

Staff

Ann Widditsch
Conference Administrator
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Conference Secretary
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Assistants

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Massachusetts Institute
of Technology

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University of Colorado

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University of Michigan

Kenneth E. Davis
Reed College

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University of California
at Berkeley

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California Institute
of Technology

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University of Texas

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Bryn Mawr College

Philip Morrison
Massachusetts Institute
of Technology

Melba Phillips
University of Chicago

Robert V. Pound
Harvard University

Robert Resnick
Rensselaer Polytechnic Institute

Van Zandt Williams (Deceased)
American Institute of Physics

John M. Fowler, *Director*

Panel on the
New Instructional Materials

Edward D. Lambe, *Chairman*
State University of New York
at Stony Brook

Arnold B. Arons
Amherst College

Ronald Geballe
University of Washington

E. Leonard Jossem
Ohio State University

Harry C. Kelly
State University
of North Carolina

Walter C. Michels
Bryn Mawr College

Philip Morrison
Massachusetts Institute
of Technology

Melba Phillips
University of Chicago

Commission on College Physics
Physics and Astronomy Building
The University of Michigan
Ann Arbor, Michigan 48104